WFL Publisher
Science and Technology Food, Agriculture & Environment Vol.1(1): 80-86. 2003 *www.world-food.net*

Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse

Dimitrios Savvas
Department of Floriculture and Landscape Architecture, Faculty of Agricultural Technology, T.E.I. of Epirus, P.O. Box 110, Arta 47100, Greece. email: savvas@teiep.gr

Received 7 September 2002, accepted 4 January 2003.

Abstract

Commercial hydroponics is a modern technology involving plant growth on inert media in place of the natural soil, in order to uncouple the performance of the crop from problems associated with the ground, such as soil-borne diseases, nonarable soil, poor physical properties, etc. Various non-toxic porous materials are used as plant growth substrates, including rockwool, perlite, pumice, expanded clay, various volcanic materials, polyurethane foam, coir dust, etc. A balanced distribution of small and larger pores is required in a substrate to ensure adequate availability of water to the plants without to affect the supply of oxygen to the roots. Hydroponics has no adverse effect on the quality of fruits and flowers produced in such systems. In contrast, the complete control of nutrition via the nutrient solution may enable an enhancement of product quality, particularly in vegetable crops, such as tomato, melon, and lettuce. The switching over from the soil to hydroponics results in a decreased application of pesticides and other toxic agrochemicals, which are necessary in soil-grown crops to disinfect the soil and to control soil-borne pathogens. Moreover, the recycling of the excess nutrient solution that drains off after each watering application may contribute to a considerable reduction of nitrate and phosphate leaching to surface- and groundwater resources. To restrict costs and increase profitability, hydroponics is increasingly based on automation of nutrient and water supply. Future developments in hydroponics are mainly focused on further automation of the nutrient solution management, particularly in closed systems in which the excess nutrient solution is recycled, as well as on a complete standardization of the substrate analysis in order to obtain more reliable results and to facilitate their interpretation.

Key words: Hydroponics, soilless culture, nutrient solution, substrates, growing media.

Introduction

Hydroponics may be defined as “any method of growing plants without the use of soil as a rooting medium, which involves supply of all inorganic nutrients exclusively via the irrigation water”. This is achieved by the supply of a *nutrient solution*, i.e. water containing dissolved fertilizers at proper concentrations, in place of raw irrigation water. Initially, the term hydroponics was introduced by Gericke[1] to describe all methods of growing plants in liquid media for commercial purposes. Gericke[2] was also the first investigator who attempted to develop an economically feasible method of growing plants in water (nutrient solution) for commercial purposes. Up to that time, the soilless cultivation of plants served exclusively as a tool for plant nutrition studies. According to Hewitt[3], Knop and Sachs were the first scientists who prepared standardized nutrient solutions in 1860 in Germany by adding various inorganic salts to water and used them to grow plants outside the soil in an attempt to identify the essential plant nutrients. This method of studying the physiology of plant nutrition was subsequently adapted and modified by many other scientists, who developed various alternative techniques to achieve better growth conditions[3]. In these studies, the plants were grown in pure nutrient solution. However, in other experiments, an porous aggregate medium was introduced to provide support and aeration to the rooting system[3-4]. To avoid any interactions between the components of the nutrient solutions and the aggregates, the latter should be chemically inactive (inert). Quartz sand and gravel (free from limestone) were the most popular aggregate materials used in studies involving soilless cultivation of plants at that time. Accordingly, *water culture* (or *solution culture*), *sand culture* and *gravel culture* were the terms used to describe these methods of growing plants. Besides Gericke, many other investigators attempted to elaborate innovative techniques and methods of growing plants without soil on a commercial scale during the thirties[4]. These studies contributed considerably to the development of commercial hydroponics. However, the technological standards of that time were inadequate to provide economical success. The main problems were the insufficient knowledge of the nutrient and water requirements of the plants, the inadequate root aeration in stationary water culture, the inefficiency and the high cost of irrigation equipment, as well as the limited scope for automation of the supply and recycling of the nutrient solution in aggregate culture. Nevertheless, despite the rather disappointing results obtained on a commercial scale, hydroponics attracted enormous popular interest, mainly in the U.S.A., but also in many other countries of the world[5,6]. Many people were fascinated by the idea of growing healthy plants and producing vegetables, fruits and flowers outside the soil. Thus, besides the professional growers, many amateur gardeners attempted to grow various plant species hydroponically. The continuous demand of interested people for more information from the scientists involved in hydroponic research motivated Hoagland and Arnon[5] to summarize the principles and practices involved in water culture at that time in a simplified review. During, and immediately after the world war, hydroponics was used to some extend by the U.S. Army to produce vegetables for both solders and civilians in some non-arable islands in Pacific and regions outside the U.S.A, which were contaminated due to the war operations[4-6]. However, during the fifties and sixties, the areas covered worldwide by horticultural crops grown in water or aggregates were insignificant and the research activity in this field, especially during the fifties, was correspondingly slight. Nevertheless, a few relevant publications relating to the composition of nutrient solutions used in hydroponics originate from that time[7,8,9,3]. The interest in applying hydroponics in commercial horticulture gradually revived from the end of the sixties. This tendency was more pronounced in the United Kingdom, the Netherlands and some of the Scandinavian countries. In the United Kingdom, the Nutrient Film Technique (NFT), which was introduced by Cooper[10,4], was initially the main hydroponic system adopted by growers on a large scale. At the same time, Scandinavian and Dutch greenhouse growers, who were encountering serious problems due to the continual use of the same soil for many years, tested the possibility of using water-absorbent rockwool plates as a soil substitute[11,12,13]. Chemically inactive rockwool, which is free from pathogens due to its processing at temperatures of about 1600°C, proved to be an ideal growing medium, with optimal hydraulic properties[14]. Thus, in the following years, there was a revolutionary expansion of rockwool grown crops in many countries. Especially in the Netherlands, the 5 ha of soilless grown crops in 1976[15] catapulted to 1,500 in 1984[16], 2,500 in 1989[17] and increased further to 4,100 by 1996[18]. In most of these greenhouses, rockwool has been the preferred growing medium, due to its good growing performance and its availability at relatively low prices from local manufacturers. Besides rockwool, many alternative porous materials are used worldwide as growing media (plant substrates) for soilless culture. These include peat, perlite, pumice, polyurethane foam, zeolite, coir dust, sawdust, expanded clay, various volcanic materials such as tuff, etc.

Advantages and Disadvantages of Hydroponics

The revolutionary expansion of hydroponics in many countries of the world in the last three decades may be ascribed to the ability of soilless growing systems to be independent of the soil and hence of all problems related to it. The main problems arising from the soil are the presence of soil-borne pathogens at the start of the crop and the decline of soil structure and fertility due to its continual cultivation for the same or a related crop species. Hydroponics has proved to be an excellent alternative to soil sterilization, especially in view of the fact that the use of chemical soil sterilants, such as methyl bromide, are or will be soon forbidden in many countries, due to their high toxicity and their adverse effects on the environment. Moreover, the cultivation of greenhouse crops and the achievement of high yields and good quality is possible with hydroponics even in saline or sodic soils, or non-arable soils with poor structure, which represent a major proportion of cultivable land throughout the world. A further advantage of hydroponics is the precise control of nutrition. This is particularly true in crops grown either on inert substrates or in pure nutrient solution. However, even in soilless crops grown in chemically active growing media, the nutrition of the plants can be better controlled than in crops cultivated in the soil, due to the limited volume of substrate per plant and its standard, homogeneous constitution, which is well known to the grower. Furthermore, the preparation of the soil is avoided in hydroponics, thereby increasing the potential length of cultivation time, which is an effective means of increasing the total yield in greenhouses. It is also worth mentioning that usually hydroponics enhances the onset of harvesting owing to the above-ground placement of the substrate or the nutrient solution, which, in heated greenhouses, results in higher temperatures in the root zone during the day. Last, but not least, the reasons imposing a switch over to hydroponics are increasingly associated with environmental policies. In particular, the recycling of greenhouse effluents in closed hydroponic systems enables a considerable reduction of fertilizer application and a drastic restriction or even a complete elimination of nutrient leaching from greenhouses to the environment. Therefore, in many countries, legislation demands the adoption of closed hydroponic systems for the cultivation of plants in greenhouses[19,20], particularly in environmentally protected areas, or those with limited water resources. The environmental advantages of nutrient solution recycling are expected to impose a further extension of closed soilless culture systems in the near future. More information on the principles and techniques involved in the recycling of nutrients in hydroponics is given by Savvas[21]. The reuse of the nutrient solution effluents in closed soilless culture systems entails the risk of disease spread via the recycled leachate[22]. The most efficient way to prevent disease dispersal, when the drainage water is reused, is the installation of a solution disinfection system. This topic is extensively outlined by Wohanka[23] in a recently published review. Due to the above characteristics, which enable an appreciable restriction in pesticide use and nutrient leaching, hydroponics is considered to be not only compatible but strongly favourable and supportive to the application of integrated crop management in greenhouses. Despite the considerable advantages of commercial hydroponics, there are still some disadvantages which restrict the further expansion of soilless cultivation methods. The current state of the technique normally enables the successful application of soilless culture systems in commercial practice. Hence, the efficiency of hydroponics in commercial use is no longer a disadvantage as it was, for instance, in Gericke's era or even during the fifties and sixties. Nowadays, the only disadvantages of hydroponics are the somewhat higher costs that are normally required for the installation of soilless culture systems as well as the increased technical skills that are needed to cope with them. In countries, where the cultivation of plants in greenhouses has reached industrial dimensions, the above disadvantages are of minor importance. In such countries, the average greenhouse size per enterprise is comparatively high. Moreover, the investment costs per unit growing area for the establishment of a commercial greenhouse are high in order to maximize yield and optimize product quality by completely controlling all the growing conditions. Hence, the equipment required for hydroponics constitutes a small aliquot of the total investment enabling the exclusion of the last imponderable factor that could restrict yield and impair quality, which is the soil. For the same reasons, most greenhouse enterprises in these countries can afford the costs of specialized personnel or external advisory services. Thus, the requirement for sufficient technical skills does not pose a problem for large greenhouse enterprises. In contrast, when the greenhouse production takes place under more simple constructions and is mainly based on favourable natural conditions, such as mild winter and increased solar irradiation, even a small increase in the installation and operation costs, that is required for the introduction of hydroponics, can often not be justified. It may be acceptable only when the problems originating from the soil become critical, water resources are limited, or the pollution of the environment by nutrient leaching is serious. This seems to be the main reason for the lower expansion of commercial hydroponics in most of the Mediterranean countries as well as in the U.S.A.

Equipment

The main part of a hydroponic installation is definitely the fertigation head unit, which enables accurate dosing of nutrients and water to the crop in form of a balanced nutrient solution. The construction of fertigation units is based on two different concepts involving preparation of the nutrient solution either by dispensing fertilizers to water into a mixing tank or by injecting fertilizers directly into the main irrigation pipe[24]. In most cases, the mixing process and the injection ratios of fertilizers are automatically controlled by means of on-line monitoring of the electrical conductivity and the pH of the outgoing irrigation solution. Usually, two tanks containing two different stock solutions of fertilizers are used. The first tank (A-tank), accommodates essentially the fertilizers containing Ca, NH_4 and iron chelate, while the second tank (tank-B) is prescribed for the fertilizers containing sulphates and phosphates. However, in large greenhouse enterprises a separate stock solution tank may be provided for each fertilizer. If such facilities are available, it is possible to automatically prepare nutrient solutions of any desired composition merely by introducing the desired characteristics of the nutrient solution into the controlling system[25-26]. Besides the fertigation unit, many other facilities are required to optimize the growing conditions in a hydroponic greenhouse. These include water storage and water supply units, the substrate and the substrate receptors (channels, bags, containers), drainage facilities or equipment enabling capture and returning of the drainage solution to the fertigation head in order to be reused, water disinfection installations used in closed hydroponic systems, the irrigation system, etc. The exact type of equipment in any particular hydroponic installation may vary, depending on the hydroponic system involved[27], the capital investment, the cultivated crop species[24], the grower's preferences and abilities, the climate conditions in the particular region where the hydroponic installation is located, etc.

Substrates

The porous materials used as substrates in soilless culture are distinguished as organic or inorganic growing media. The organic materials used in soilless culture originate from plant residuals and are therefore subjected to biological degradation. The decomposed organic materials are more or less chemically active, due to the presence of ion exchange sites, which may adsorb or release nutrients. In contrast, most inorganic materials are chemically inactive (inert). Therefore, many authors use the terms "organic" and "inorganic" growing media as synonyms to "chemically active" and "inert" substrates, respectively. However, some inorganic materials, such as zeolite and vermiculite, possess a high cation exchange capacity[28-29]. It is therefore better to avoid the use of the above terms as synonyms. The ability or inability of a substrate to retain or release nutrients is a characteristic of major significance. Obviously, when growing on an inert medium, all nutrients must be supplied to the crop through the nutrient solution at the same concentrations as in water culture. In this case, the substrate serves merely to improve the supply of oxygen to the roots of the plants. Therefore, the use of the term hydroponics for crops grown on inert substrates seems to be reasonable and compatible with the initial sense of the word, as defined by Gericke[1]. However, when the substrates are capable of substantially modifying the composition of the supplied nutrient solution due to their ion exchange capacity, it seems more appropriate to use the term *soilless culture* rather than h*ydroponics*. Nevertheless, in most crops grown on chemically active growing media, the volume of substrate per plant is as low as in crops grown on inert substrates. As a result, most of the nutrients required by the plants must be supplied via the nutrient solution. In view of this fact, many authors still use the term *hydroponics* as synonym to *soilless culture*. The differences in fertilization management between substrate- and soil-grown crops arise mainly from the limited volume of substrate per plant in the former, which imposes a lower buffering capacity for pH and solution composition in combination with limited nutrient reserves[30]. This feature is more marked, when chemically inactive substrates are involved. Regarding the physical properties of the substrates, a high content of easily available water in combination with an adequate air supply are considered as the most important characteristics of growing media used in hydroponics. Water retention and release curves provide excellent information regarding the ability of a substrate to provide air and water to the roots of the plants at different heights of its volume and at different water content regimes. Nevertheless, the availability of water to the plants depends also on the hydraulic conductivity characteristics of the medium, which in porous materials drops dramatically with reduced water content[30]. As a consequence, a very high water content approximating container capacity is a prerequisite for optimal water availability in substrate-grown crops, provided that the air filled porosity of the particular growing medium is still adequate at this water content regime.

Crop Nutrition and Nutrient Solution

In soilless culture, all essential plant nutrients should be supplied via the nutrient solution, with the exception of carbon, which is taken up from the air as carbon dioxide. To prepare nutrient solutions containing all the essential nutrients, inorganic fertilizers are used to provide most of them. Iron forms an exception to this rule, since it is added in chelated form, to improve its availability for the plants[7]. In most cases, the fertilizers used to prepare nutrient solutions are highly soluble inorganic salts. However, some inorganic acids, particularly nitric, phosphoric and boric acid, are also used. As a rule, in commercial hydroponics, proper amounts of the fertilizers needed to prepare the nutrient solution are mixed with water into tanks to form concentrated stock solutions. Thus, when the soilless cultivated plants should be watered, the stock solutions are diluted with the irrigation water in proper ratios through automatic fertilizer injection systems, to form a fresh nutrient solution, which is supplied to the crop. The composition of nutrient solutions and the optimization of nutrition in commercial hydroponics has been a primary objective of the research work related to soilless culture during the last decades. These efforts, supported by the development of modern analytical techniques and equipment, have resulted in the formulation of new nutrient solution compositions, which are adapted to the specific requirements of most horticultural species grown under glass[29-31-32]. Some authors suggest nutrient solution formulae in terms of fertilizer amounts to be added to a particular volume of water (e.g., Hoagland and Arnon[5]). Such formulae can be realized even by a trained technician who has only a limited chemical background. Thus, when one has to prepare a universal nutrient solution in order to grow plants in a water culture and is not interested in specific target characteristics (e.g., a specific total salt concentration, or certain nutrient ratios) the use of such a formula is very convenient. However, this is possible only when deionized or rain or at least a very soft water is used to prepare the nutrient solution, otherwise the mineral composition of the water employed should be taken into account. Moreover, as has been already discussed in previous sections, to obtain high yields and good quality in commercial crops grown hydroponically, the nutrient solution supplied to the plants must be specific for the particular crop, the growth stage, the climatic conditions, the substrate or hydroponic system used, etc. Obviously, the nutritional management of a soilless cultivated crop according to this concept is not compatible with the use of a standard formula suggested in the literature, especially when the water used to prepare the nutrient solution contains substantial amounts of inorganic ions (Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^-, etc.). Therefore, various investigators[4-9-29-33] proposed several methods of calculating a nutrient solution satisfying particular requirements, which are given as target values, such as EC, nutrient concentrations, relative proportions of nutrients, etc. However, all these methods require some understanding of chemistry and are more or less arduous, because routine calculations have to be repeated in each particular case. To overcome this problem, a standardized method was proposed, which enables the formulation and calculation of nutrient solutions corresponding to any desired characteristics by taking into account the mineral composition of the water used to prepare it[25-26]. This method, due to the complete standardization of the calculations, can be used in a computer algorithm which enables fully automated formulation of a nutrient solution composition and calculation of the fertilizers needed to prepare it. Moreover, if single fertilizer stock solutions are used and a suitable computer controlled system for the preparation and the supply of the nutrient solution is available, this algorithm enables automated preparation of a nutrient solution merely by defining the target characteristics. The target values can change as frequently as desired without to remove the currently used stock solutions in order to change the concentrations of the included fertilizers. This method will be presented briefly below.

The composition of a nutrient solution is completely defined if target values for the following solution characteristics are given: (i) E.C. of the nutrient solution (E_t) (ii) pH of the nutrient solution, (iii) the K:Ca:Mg ratio (X:Y:Z), (iv) the N:K ratio (R) (v) the ratio of P to total nutrient anions (P), (vi) concentration ratio of NH_4-N/total-N (N) and (vii) micronutrient concentrations (C_{jt}, j = Fe, Mn, Zn, Cu, B, Mo)[25-26]. In this concept, the priority is given to the N:K ratio rather than to the nutrient anion proportions, due to reasons outlined in a previous paper[34]. If target values for the above characteristics are given and the mineral composition of the water used to prepare the nutrient solution is precisely known, it is possible to calculate the target concentrations of the nutrient solution as follows:

1. A linear relationship may be used in commercial practice to convert the electrical conductivity (E in dS m^{-1}) of balanced nutrient solutions into total salt concentration C (meq l^{-1}) and vice versa[25-26]:

$$C = 9{,}819\,E - 1{,}462 \qquad (1)$$

The electrical conductivity of the nutrient solutions used to obtain (1) ranged from 0.8 to 4.0 dS m^{-1}. Consequently, (1) is valid only in this particular EC range. Using (1) and replacing E by E_t, it is possible to convert the electrical units (dS m^{-1}) indicating the total salt concentration of the desired nutrient solution to chemical units (meq l^{-1}).

2. As outlined in detail in previous papers[25-26-35], the HCO_3^- concentration C_b in meq l^{-1}, which is established in the irrigation solution after adjustment to the desired pH, can be estimated by means of a formula proposed by De Rijck and Schrevens[36] to compute the bicarbonate fraction in aqueous solutions:

$$\frac{C_{HCO_3^-}}{C_{CO_3^{2-}} + C_{HCO_3^-} + C_{H_2CO_3}} = \frac{Ka1}{C_H + B} \qquad (2)$$

where $K_{a1} = 10^{-6.3}$, $K_{a2} = 10^{-10.3}$, and

$$B = 1 + \frac{Ka1}{C_{H^+}} + \frac{Ka1Ka2}{C\,(_{H^+})^2}$$

3. The target macroelement concentrations in the irrigation nutrient solution C_{it} in meq l^{-1} are estimated using the Eqns in Table 1, as functions of the target K:Ca:Mg ratio (X:Y:Z), the desired N:K ratio (R), the target ratio of phosphorus to total macronutrient anions (P), and the ratio of ammonium to total nitrogen (N). The above ratios are expressed on equivalent basis. These ratios, as well as the concentrations of all nutrients and the ballast ions Na^+ and HCO_3^- in the raw water (C_{iw}) are input data. The Eqns of Table 1 are based on the assumption that no Na^+ and Cl^- are added via fertilisers. Any Na^+ and Cl^- input owing to fertiliser impurities is neglected. The target concentration of H^+ (H_3O^+) in the irrigation solution is less than 10^{-2} meq/l, since the desired pH in nutrient solutions is commonly higher than five[37], and is, therefore, neglected.

4. The input of macroelements (except H^+ and HCO_3^-) to the irrigation water via fertilisers I_{if} (in meq l^{-1}), when preparing fresh nutrient solution, may be readily calculated using Eqn

$$I_{if} = C_{it} - C_{iw} \qquad (3)$$

where C_{it} indicates the target concentration of the i macroelement in the nutrient solution as calculated via the Eqns of Table 1 and C_{iw} are the macroelement concentrations in the raw water. The input of H^+ (acid) is aimed at reducing the HCO_3^- concentration up to C_b, which corresponds to the target pH. Thus:

$$I_{H^+f} = C_{HCO_3^-w} - C_b$$

since HCO_3^- is neutralized by H^+ at an 1:1 molar ratio[32-37].

5. The input dosages of fertilisers, I_{pn} in meq/l, (p = Ca, Mg, K, NH_4, H, and n = SO_4, NO_3, H_2PO_4) may be calculated using the Eqns given in Table 2.

6. Based on the previously calculated input dosages of fertilisers (I_{pn}), the amounts of fertilizers (W_{pn} in kg) needed to prepare certain quantities (V_{pn} in m^3) of stock solutions are calculated using the following formula:

$$W_{pn} = \frac{I_{pn}\, Q_{pn}\, V_{pn}\, A_{pn}}{1000} \qquad (4)$$

where Q_{pn} is the equivalent weight of the pn^{th} fertilizer and A_{pn} denotes the dilution ratio of the stock solution containing the pn^{th} fertilizer. The chemical formula of the commercially used calcium nitrate is $5[Ca(NO_3)_2 \cdot 2H_2O]NH_4NO_3$. Therefore, when using (4) to calculate the weight of calcium nitrate ($W_{Ca(NO3)2}$) the equivalent weight corresponding to Ca (108.05) should be introduced as $E_{Ca(NO3)2}$. Moreover, to take into account the amount of NH_4NO_3 that is included in the commercially used calcium nitrate, $[NH_4NO_3]$ should be replaced by $[NH_4NO_3] - 0.1[Ca(NO_3)_2]$ when using (4) to calculate the weight of ammonium nitrate (W_{NH4NO3}).

7. The amounts of micronutrient fertilizers which are required to achieve the target trace element concentrations are calculated using the formula

$$W_j = \frac{I_j\, M_j\, V_j\, A_j}{1000 n_j} \qquad (5)$$

where W_j is the amount (g) of the fertilizer containing the j micronutrient (j = Fe, Mn, Zn, Cu, B and Mo), that is needed to prepare a certain volume (V_j in m^3) of stock solution containing the j micronutrient; n_j is the number of gr-atoms of the j micronutrient in one mol of the related fertiliser; I_j is the input dosage of the j micronutrient, which is calculated by deducting the target concentration (mmol l^{-1}) of the j micronutrient in the nutrient solution from that found in the raw water ($I_j = C_{jt} - C_{jw}$); M_j is the molecular weight of the fertilizer containing the j micronutrient; and A_j is the dilution ratio (concentration factor) of the stock solution containing the fertilizer of the j micronutrient. However, the concentration of Fe in the tap water is not taken into account when applying (5) to calculate the weight of iron fertilizer because after addition of the stock solutions most of this iron precipitates, mainly in form of iron phosphate[38].

8. If each macronutrient fertiliser is contained in a separate stock solution tank, it can be independently injected to the raw water, when fresh nutrient solution is prepared, by means of a dosing pump having a constant injection rate J_{pn} in l s^{-1}. Thus, the amount of each stock solution that is required to achieve the target concentrations in the irrigation solution can be precisely dispensed by automatically controlling the injection time T_{pn} in s of the corresponding dosing pump, which can be calculated using Eqn

$$T_{pn} = \frac{I_{pn}\, Q_{pn}\, V_{pn}\, V_t}{J_{pn}\, W_{pn}}\,, \qquad (6)$$

where I_{pn} denotes the required input dosages of fertilisers in meq l^{-1}, Q_{pn} the equivalent weight in g eq^{-1} of the pn fertiliser, V_t the volume in m^3 of the nutrient solution to be prepared, and W_{pn} the weight in kg of the pn fertiliser contained in V_{pn} m^3 of stock solution. However, the injection of nitric acid should preferably be controlled by means of on-line monitoring of pH and not by calculation of T_{HNO3} via (6).Extensive reviews of the composition of nutrient solutions used in soilless culture is given by Savvas[34] and Sonneveld[39], while for the management of nutrition in modern hydroponics, readers are referred to Adams[40].

Product Quality in Hydroponics

Some consumers are rather skeptical when thinking of hydroponically produced vegetables. This attitude is mainly based on the assumption that the soilless cultivation of plants is based on the extensive use "chemicals", in contrast to the plants grown in soil which acquire "natural substances" for their nutrition. However, this belief contrasts obviously with the principles of the science of plant nutrition. It is well known that the higher plants need only inorganic substances, mainly in ionic form, to satisfy their nutritional requirements[41]. Thus, for instance, the plants take up NO_3^- and to some extent also NH_4^+ and not organic substances in order to supply their cells with nitrogen, regardless of the content of organic material in the soil. However, the inorganic ions do not have any memory concerning their origin when they are used in the plant and the human metabolism. Consequently, with respect to the quality of the edible vegetable products, it is completely irrelevant whether the nitrogen contained in the plant tissues stems from the organic substances of the soil or from inorganic fertilizers. The only factor influencing the vegetable quality is the quantity of absorbed nitrogen and the way in which it is utilized in plant metabolism, mainly with respect to the nitrate nitrogen content in the edible plant tissues. However, both these factors are better managed in hydroponics[42], since in the small volumes of rooting medium applied in soilless culture the nutrient supply is more efficiently controlled through the composition of the nutrient solution. Thus, reducing the nitrate nitrogen content in the nutrient solution supplied to lettuce during the last week prior to harvesting lowered considerably the NO_3^- content in the leaves of the plants, without significant yield losses[43]. Similar responses have been reported also by Wendt[44] in kohlrabi and celery. Moreover, since in hydroponics the plants are grown in substrates, which are free from pathogens when they are initially supplied to the grower, the pressure from soil-borne diseases is much weaker than in soil grown crops. As a result, the demand to use soil disinfecting chemicals is considerably reduced in hydroponics, with obvious advantages for the quality of the produced vegetables. Last but not least, the taste of some fruit vegetables such as tomato, melon, etc., may be substantially improved in hydroponics by manipulating the total salt and nutrient concentration in the supplied nutrient solution[37-45-46]. Nevertheless, many factors that influence the growth of plants in hydroponics are different from those of soil grown crops. Most of these factors also affect the quality of harvested vegetables and flowers. Indeed, the product quality is of even more importance than total yield for attaining competitiveness in modern horticulture. Schnitzler and Gruda[47] have recently published a detailed review on the quality of fruits and vegetables produced hydroponically.

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Table 1. Equations used to estimate the target macroelement concentrations in the nutrient solution (C_{it} in meq l^{-1}), based on given target electrical conductivity, pH, and macronutrient ratios in the irrigation solution.

Cations	Anions
$C_{k+t=}X(C_t - C_{na+w})(1+NRX)^{-1}$	$C_{NO_3^- t} = RC_{K+t} - C_{NH_4^+ t}$
$C_{Ca^{2}+t} = C_{k+t}YX^{-1}$	$C_{HCO_3^- t} = C_b$
$C_{mg^{2}+t} = C_{k+t}ZX^{-1}$	$C_{H_2PO_3 - t} = P(C_t - C_b - C_{Cl-w})$
$C_{NH_4+t} = NRC_{k+t}$	$C_{SO_4 2-t} = C_t - C_{NO_3-t} - C_{H_2PO4-t} - C_b - C_{Cl-w}$
$C_{Na+t} = C_{Na+w}$	$C_{Cl-t} = C_{Cl-w}$
$C_{H+t} = 0$ (less than 10^{-2} meq/l)	

Table 2. Equations used to estimate the input of each individual fertilizer (I_{pn} in meq l^{-1}), required to achieve the target values of EC, pH and macronutrient ratios in the irrigation nutrient solution.

$I_{Ca(NO_3)_2} = I_{Ca^{2+} f}$
$I_{MgSO_4} = I_{Mg^{2+} f}$ if $I_{SO_4^{2+} f} > I_{Mg^{2+} f}$; $I_{MgSO_4} = I_{SO_4^{2-} f}$ if $I_{SO_4^{2+} f} < I_{Mg^{2+} f}$
$I_{Mg(NO_3)_2} = 0$ if $I_{SO_4^{2+} f} > I_{Mg^{2+} f}$; $I_{Mg(NO_3)_2} = < I_{Mg^{2+} f} - I_{MgSO_4}$ if $I_{SO_4^{2+} f} < I_{Mg^{2+} f}$
$I_{K_2SO_2} = I_{SO_4^{2-} f} - I_{Mg^{2+} f}$ if $I_{SO_4^{2+} f} > I_{Mg^{2+} f}$; $I_{K_2SO_4} = 0$ if $I_{SO_4^{2+} f} < I_{Mg^{2+} f}$
$I_{KH_2PO_4} = I_{H_2PO_4^- f}$ if P is added as KH_2PO_4; $I_{KH_2PO_4} = 0$ if P is added as H_3PO_4
$I_{H_3PO_4} = = 0$ if P is added as H_3PO_4; $I_{H_3PO_4} = I_{H_2PO_4^- f}$ if P is added as H_3PO_4
$I_{KNO_3} = I_{K+f} - I_{K_2SO_4} - I_{KH_2PO_4}$
$I_{NH_4NO_3} = I_{NH_4 + f}$
$I_{HNO_3} = I_{H+f} - I_{H_3PO_4}$