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Mineral Nutrition of Cucurbit Crops

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ABSTRACT

Proper mineral nutrition of crops is in many ways a blend between science and art. Knowledge is the basic pre-requisite for the correct use of fertilizers, but because so many factors (including uncontrolled ones like temperatures and sunlight) are involved in providing proper plant nutrition, a grower's green finger is also important. The main decisions that one has to make are which fertilizer source to use, when to fertilize (calendar and plant developmental stage) and how much fertilizer to apply (plant requirement and nutrient availability). Adequate fertilization of cucurbits already from the early emergence stage has advantages in terms of uniform, health and seedling vigor, but there is much evidence that plants have efficient mechanisms to repair nutritional stresses. Fertilization under field and protected conditions require different approaches. Fertilization in the field consists of a basic nutrient application (before seeding) and 1-3 side dressings during the growing season, whereas fertilization under protected environments and especially in container-grown crops requires a continuous application of nutrients through the irrigation system. The growing demand over the past decade for cucurbit fruits year-round has shifted a greater part of production from the field to greenhouses and plastic tunnels. Mineral nutrition under expensive protected conditions requires more precise and finely-tuned methods as compared to traditional field-grown crops where soil served as a nutrient reservoir and buffer. A new trend which has been developing over the past few years is the growing interest in environmental conservation and an enlarging movement toward sustainable and organic agriculture. Plant nutrition studies in organic ecosystems are generally long-term and accordingly our present understanding is still in its infancy.

Keywords: *Citrullus lanatus*, cucumber, *Cucumis melo*, *Cucumis sativus*, *Cucurbita* spp., fertigation, melon, squash, watermelon

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INTRODUCTION

Fertilization is a cultural practice that grew up with agriculture. Plants in nature utilize available mineral resources derived from soil particles and decomposing organic materials. These mineral sources were available during the first steps of civilization when human nutrition was based on animal hunt and plant collection. Centuries of agricultural development which came about as a result of man's better understanding of plant needs and functions led to improved methods of crop production. Fertilization of agricultural fields from the earliest days to date was based on incorporation of organic residues such as farm yard manure (FYM) or processed municipal garbage to the soil (Rahn 1946; Kayama and Ohnishi 1978; de Almeida Lima *et al*. 1984; Studstill *et al*. 2006), while the use of inorganic compounds as fertilizers was introduced much later. Over the years many books and review articles on the mineral nutrition of higher plants have summarized the accumulated knowledge in this field (Clarkson and Hanson 1980; Marschner 1995; Barker and Pilbeam 2007; Silber and Bar-Tal 2008). The growing body of mineral nutrition studies has provided much specific information such as the nutritional requirement of a particular cucurbit crop (Ingestad 1973), or plant preferences for particular ionic forms (Barker and Mills 1980). In modern agriculture main concerns in fertilizer application are the amount, availability, timing and balance of the applied plant nutrients. Use of fertilizers in modern agriculture may cause serious damage to the environment. For example, excess nitrates may be leached from the upper soil layer and contaminate the groundwater below (Kumazawa 2002; Simonne *et al*. 2003). Another type of problem that often arises when fertilizers are used in agriculture is the conflicting nutrient requirements for maximal yield and high quality. For example, muskmelon cultivated under nutrient film technique (NFT) produced highest yields at lower nitrogen and potassium concentrations than required for achieving the highest sugar content in the fruit flesh (Lee *et al*. 2006). One method for minimizing environmental contamination by overuse of fertilizers is to supply the crop with slow-release fer-

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tilizers. The first attempts at applying slow release fertilizers was achieved by placing standard fertilizers in biodegradable bags which were buried in the soil. This controlled-release system was dependant on the bag material characteristics and the time required for its degradation (Peregrine *et al*. 1981). This method was gradually improved by coating the fertilizer particles with different polymers and monitoring the physical and chemical changes in the soil/medium over the course of time (Locascio *et al*. 1978; Albano *et al*. 2006; Newman *et al*. 2006). Slow-released fertilizers have never been widely used in cucurbits because its cost, and because in most cases there was no economic advantage in their use (Lorenz *et al*. 1972; Locascio *et al*. 1973). Another method which allows for better control in applying plant nutrients was the introduction of liquid fertilizers through the irrigation system – fertigation. This method facilitated the application of fertilizers and enabled one to apply small doses according to crop needs (Csizinszky *et al*. 1985; Csizinszky *et al*. 1987; Haynes and Swift 1987; Pinto *et al*. 1993). Fertigation makes it possible to apply fertilizers directly in the crop row rather than over the whole field as in traditional broadcasting. This idea is in line with earlier efforts to reduce fertilizer application by banding it beneath or close to the crop row (Buwalda *et al*. 1987: Parish *et al*. 2000). Fertilizer banding, too, was never widely adopted; probably because the advantages were generally not significant and because it increases toxicity risk in the root zone. In watermelon, for example, plant growth and fruit yield were enhanced by broadcast compared to band application of either NPK fertilizers or micronutrients (Locascio *et al*. 1972). Another approach for applying crop nutrients directly to the plant is by foliar application. Based on the fact that toward the end of the season senescence processes limit the efficiency of root activeties, it was believed that foliar fertilization may be beneficial. This idea was tested in many crops over the years, and in general it was observed that this method did not meet the expectations of massive macronutrients supply. For example in muskmelons foliar application of fertilizers did not increase any yield or quality parameters consistently (Nerson *et al*. 1985).

TECHNIQUES FOR DETERMINATION OF FERTILIZERS REQUIREMENTS

Many techniques have been developed, over the years, for testing fertilization requirements of various crops. Most tests for determining the nutrient content are based on plant and/or soil direct analysis. The limitation with this approach is that the data are mostly relevant to the specific area which was studied, since each location has its own set of environmental and soil conditions (Evanylo 1990). Indirect tests like infrared imaging of the crop and visional observations of deficiency or access symptoms (Adams 1985) have also been used.

Plant analysis

Determination of nutrient content in plant tissues by a serial sampling during life cycle of the crop is probably the most common method used for evaluating the crop fertilizer needs. A classic study representing this method was carried out in four varieties of muskmelon, documenting the nutrient contents in different plant parts along the whole growing season (Tyler *et al*. 1964). Further information may be gained by multiple locations studies. Such a study showed, in melons, high positive correlations between N or Ca contents in the leaves and the fruit yield and its quality (Secer and Unal 1990). Plant tissue analysis in melon, also revealed that potassium calcium and nitrogen are the most demanded nutrients, and that the period of largest requirement occurred at flowering and fruit set (Silva *et al*. 2006). When such studies are focused on a more specific target they are generally conducted under controlled conditions. For example, Iwahashi *et al*. (1982) investigated the accumulation of the main cations, during the ontogenetic development of cucumber organs, using a hydroponic system. Another approach in trying to understand crop needs for nutrients is to grow the plants in serial fertilizer combinations and at the end of the growing season to analyze and calculate the total uptake of the different nutrients in relation to the vegetative development and the commercial yield of the crop. In such a study, it was found that cucumbers grown in a fine sandy loam soil absorbed throughout the season 90, 12 and 145 lb/A of N, P and K, respectively, and 44, 50 and 38% of these nutrients were transported to the fruits (McCollum and Miller 1971). This method can be modified for short term experiments, under controlled environment, in which seedlings are grown for a limited time in different series of nutrient solutions and the uptake, compartmentalization and translocation of nutrients is determined (Morard and Benavides 1990). Nitrogen concentration in plant tissues is traditionally determined by digesting the tissue in concentrated acids and measuring total N content or NH_4-N and NO_3-N using ion specific electrodes or spectrophotometer. This and other laboratory methods are laborious and in many cases do not give results in real time. Another concern regarding plant analysis is whether the data obtained represent the real status of the living plant rather than artificial values influenced by the technique used. Kafkafi and Ganmore-Neumann (1997) raised this question for ammonium determination in wheat and melon leaves and concluded that many data in the relevant literature are biased. In the past decade a rapid technique for determination of nitrogen status in cucurbit plants, by field direct measuring of NO_3-N in leaf petiole, has gained popularity (Fontes *et al*. 2003; Studstill *et al*. 2003). Measurement of nitrate and potassium content in petiole sap of greenhouse-grown cucumbers, under different fertilization regimes, revealed that concentrations of 1000-1600 ppm NO_3 and 4000-5500 ppm K represented values for optimal nutrition status (Drews and Fischer 1992). In pumpkins, nitrate concentration in petiole sap at maximal fruit yield was much lower in irrigated fields than under dryland farming (Swiader *et al*. 1988). A rapid and accurate assessment of real-time plant nitrogen status was successfully tested in pumpkins by measuring the relative 'greenness' of leaves using a hand-held spectrophotometer (SPAD-502 chlorophyll meter) (Swiader and Moore 2002).

Soil testing

Application of fertilizers to soil containing a high level of nutrient elements is unnecessary in some cases, and may cause yield reduction in other cases (Rubeiz and Maluf 1989; Rubeiz 1990).

A simple and useful method for determining fertilizer need is by analysis of nutrient elements in the soil (Buwalda 1986). Improvement or changes in soil analytical methods often result in new understanding about fertilizer needs. For example, the Mehlich-I soil test calibrations brought about a significant reduction in PK fertilizer recommendations for melon and watermelon in Florida (Hanlon and Hochmuth 1992). Analysis of soil nutrient content is a laborious process, and as a result, commercially available soil-test kits with a wide range of accuracy were developed to facilitate these procedures (Faber *et al*. 2007).

FERTILIZATION IN THE NURSERY

The primary nutrient sources for early seedling development, occur in the seed cotyledons in elemental form or as stored organic molecules, and are mobilized at germination and shortly thereafter to the embryo axis and to the growing shoot and root (Davies and Chapman 1979; Ockenden and Lott 1990). However, this reservoir is very limited and without an external supply of nutrients the seedlings will not develop properly (Okenden and Lott 1988). The rapid development of cell, tissue and organ culture in the second half of the previous century was accompanied with a lot of expectations concerning a better understanding of mineral nutrition needs of plants grown *in vivo* (Williams 1993). Many studies revealed nutrient requirements *in vitro* (Ohira *et al.* 1973) and even differences among inbred lines of the same crop were established (Vasic *et al.* 2001). However, the main focus in studies on tissue culture media improvement, was on minor chemicals needs like vitamins, phytohormones and plant growth regulators. The high volume investigation of tissue culture did not contribute, to date, a significant improvement of whole plant nutrition. Adequate fertilization of young seedlings in the nursery is of primary importance in obtaining healthy and vigorous transplants. An efficient method to achieve this goal is by incorporation of slow release fertilizers in the seedling medium. In muskmelon, such an enriched medium increased by four fold seedling growth four weeks after emergence (Edelstein *et al.* 1997). An important issue that must be addressed is, to what extent does vigor status of the seedling affect subsequent development and productivity of the plant weeks later in the field. A greenhouse study in muskmelon showed that N and/or P deficiencies in early stages of seedling development (4 weeks after emergence) can be reversed rapidly by transferring the stressed seedlings to an optimal nutrition regime (Nerson *et al.* 1987, 1988). Another study in muskmelons revealed that only a severe lack of nutrients in the nursery decreased the early yield in the field, whereas mild nutritional deficiencies in the nursery were eliminated 2-4 weeks after transplanting to the field (Edelstein and Nerson 2001). Even though all of the nutrient elements are important and their deficiencies or accesses are harmful, nitrogen is by far the most dominant element in cucurbit seedling development (Nerson *et al.* 1987). Transplanting of seedlings from nursery trays to the greenhouse or the field is often accompanied by a temporary cessation of growth as the seedling acclimates to the new environment. In muskmelon, it was found that during this acclimation phase, nitrogen absorbed by the seedling during growth in the nursery is redistributed from older leaves to younger ones in order to enhance their function (Ikeda *et al.* 1979). Many studies have been done to determine the importance of nitrogen source and in almost all cases, the supply of nitrate salts were more beneficial to plant development than ammonium salts. The beneficial effect of nitrate over ammonium in watermelon and muskmelon nutrition was detected at early seedling stages in the nursery (Lamb *et al.* 1990; Guzman and Olave 2006). The mechanism for calcium, magnesium and potassium uptake by young seedlings was studied in cucumber (Bengtsson 1982; Bengtsson and Jensen 1983). It was found that transpiration and water translocation was insufficient to explain the absorption and translocation of these nutrients. The regulation of uptake and translocation was primarily achieved by active cation exchange on the root surface and by active translocation mechanisms. Uptake of macro and micronutrients may be disturbed by the presence of different heavy metals ions in the nutrient solution. In young cucumber seedlings, lead or cadmium inhibited the absorption of nitrate, potassium, calcium and iron, but not magnesium (Burzynski and Grabowski 1984; Burzynski 1987). Seed pretreatment with fungicides to protect the young seedlings against soil-born pathogens may be another source of nutrient uptake disturbance. In watermelon, pretreated seeds with the organic fungicides Captan or Thiram decreased uptake of calcium by the young seedlings (Liu *et al.* 1994). On the other hand the presence of organic acids like fulvic acid (100-300 ppm) in the nutrient solution increased the uptake of macro and micronutrients and the growth of roots and shoots of cucumber seedlings (Rauthan and Schnitzer 1981). Nutrient unbalance or inadequate level of one nutrient may influence the uptake of another one. For example, deficiency of potassium or calcium increased the amount of accumulated nitrogen in some parts of cucumber seedlings (Kubik-Dobosz 1981).

FIELD PRODUCTION

In order to properly fertilize of crops in the field it is essential to know the content of mineral nutrients in the soil, their availability to the crop and the capability of the crop to uptake different elements. The capability of plants to absorb nutrients from the soil or in hydroponics systems is variable, not only at the family or genus level but even among subspecies. For example, plants of *Cucurbita pepo* ssp. *pepo* absorbed under field conditions significantly more K, P, and Zn than plants of the subspecies *ovifera* (Gent *et al.* 2005). Generally, the interest in fertilization is limited to its effects on vegetative growth and yield of the treated plant, but the effects may be far beyond that. For example, it was found that the amount of nitrogen fertilizer supplied to zucchini squash plants affected the number and size of pollen grains and subsequently the seed yield per fruit and the vigor of the next generation seedlings (Lau and Stephenson 1993).

Nitrogen, phosphorus and potassium are generally the most important nutrients in fertilization of cucurbits under field conditions (McCollum and Miller 1971; Subrahmanyam *et al.* 1987; Suojala-Ahlfors *et al.* 2005). Conversely, the results of NPK applications to muskmelon and watermelon in the field are often unexpected and disappointing. In many studies (Bradley and Fleming 1959; de Buchananne and Taber 1985; Wiedenfeld 1986; Bracy and Parish 1997; Panagiotopoulos 2001; Silva *et al.* 2007) it has been shown that these crops do not respond to nitrogen and/or phosphorus fertilizer applications; either in yield increase or quality improvement of the end product. These examples, from different parts of the world, demonstrate how complicated and unpredictable the proper use of fertilizers can be. The main reason for this inconsistent response to fertilization under field conditions is due to the numerous environmental factors involved. A major factor interacting with fertilizer utilization is the irrigation regime or water availability (Pier and Doerge 1995; Kirnak *et al.* 2005). The best results for nitrogen application to muskmelon were obtained in seasons of heavy rainfall (Brantley and Warren 1960) or under low moisture tension (Perez-Zamora *et al.* 2004). Nitrogen requirements for cucurbit crops are variable and depend upon many environmental factors including the sequence of crop rotation (Swiader and Shoemaker 2004). Cucumber plants absorbed nitrogen mainly as nitrate anions and the main reduction activity take place in the leaves (Olday *et al.* 1976). Highest yields for processing and slicing cucumbers in Florida, processing pumpkins in Illinois and watermelons in India were obtained with 100-150 kg N per hectare, while higher rates decreased the yield and increased the off-shape fruit percentages (Cantliffe 1977; Srinivas *et al.* 1989; Hochmuth and Hochmuth 1991; Swiader and Shoemaker 2004). Phosphorus content in cucurbit tissues is generally one order of magnitude lower than nitrogen. Nevertheless, due to lower availability of phosphorus, the nitrogen to phosphorus ratio in most fertilization schemes is around 2:1. Young seedlings of many plants, including melon, are able to efficiently uptake and accumulate phosphorus. This phosphorus reservoir in the seedling may be redistributed in plant tissues later on (Nerson *et al.* 1988). Phosphorus requirement under field conditions is extremely variable. Hybrid squash (*Cucurbita maxima* var. Delica), an important export crop in New Zealand, required very large (up to 500 kg/ha) phosphorus applications in order to produce maximal fruit yield (Buwalda and Freeman 1988). On the other hand, watermelons grown in Florida needed only slight amounts of phosphorus (26 kg/ha) to generate maximum yields (Hochmuth *et al.* 1993).

The potassium requirement for cucurbit crops is variable, depending mainly on soil type. In many cases cucurbits do not respond at all to potassium application. However, in poor light soils such as sand, the highest fruit yield of pumpkin and melon crops were achieved in plots which were fertilized with high levels of potassium (Swiader *et al.* 1994; Sousa de *et al.* 2005). Potassium increased summer squash yields in Chile by its effect on sex expression and enhancing female flowering (de Gracia *et al*. 2003). Calcium, another macronutrient, is an essential element and its content in cucurbits dry tissues is mostly between 0.5 to 4%. Like other macronutrients in cucurbit crops, calcium concentration in the different tissues of cucumber decreased with ontogenetic progression and was always lower in fruit than in leaves (Engelkes *et al*. 1990).

Soil properties have a great influence on crop development and fertilization management. For example, acidic soils are unfavorable for muskmelons and frequent lime applications are essential to neutralize the acidifying effect of ammonium fertilizers. Reducing soil acidity can increase the uptake of calcium and magnesium; enhance nitrification, reduce manganese toxicity and maximize fruit yield and quality (Bhella and Wilcox 1989). On the other hand, high soil pH (common in calcareous soils) or application of phosphate bicarbonate may induce iron-chlorosis as a result of defected reducing ability in the roots (Romera *et al*. 1992). Fertilization efficiency may also be affected by the method of pre-season soil preparation. For example, nutrient uptake and fruit yield of summer squash were higher when the tillage was by moldboard plow to a depth of 30 cm as compared to disc harrow to a depth of 15 cm (Smittle *et al*. 1984). The ionic form of macronutrients applied to the crop is important because it influences their availability (Haynes and Goh 1978). In a three year study in Oklahoma, banana squash (*Cucurbita maxima* Duch.) was treated with synthetic or alternative (based on natural rock sources) fertilizers and the fruit yields, in all years, were significantly higher in the plots supplied with the regular synthetic fertilizers (Russo 1993). The response of cucurbit crops to macronutrient supply is dependent not only on soil type but also on the previous crop (rotation). In processing cucumber, a much higher level of fertilizers was required after cereals than after beans (Tiwari *et al*. 1984).

PRODUCTION UNDER PROTECTED ENVIRONMENTS

A protected environment includes a wide range of supports for the crop, of which the main consideration for the grower is the economic benefit. Any investment which makes the environment more favorable for the crop must result in an economic benefit to the grower, either expressed as increased yield and/or improved quality. Cucurbit crops grown under protected conditions either for their fruits or their seeds are becoming more common because of their increasing year-round demand and their potential high profit for the producers. There is a tremendous conceptual difference in the fertilization of cucurbits planted in soil as compared to plants grown in limited root-zone containers filled with artificial potting-mix or inert media. In the former case the grower is able to calculate the crop needs in advance and the soil serves as a mineral bank, whereas in the later case the preferred way is to apply nutrients frequently (with every irrigation), because a large proportion of the fertilizers are continually washed out from the root-zone (Erickson and Wedding 1958). Under such conditions, fertilization is based on the concentration of nutrient elements in the fertigation solution (Huett and White 1991) rather than on the total fertilizer amount, which is characteristic of soil-grown crops. For example, it was found that the optimal concentration of nitrogen for cucumbers, grown in perlite medium, was 225-250 mg/l as a compromise between higher concentrations which reduced fruit firmness and lower concentrations which damaged the fruit-rind hue (Jasso-Chaverria *et al*. 2005). Fertilization under controlled conditions requires a full understanding of plant needs. Pioneer studies in many crops, concerning the optimal nutrient solution content and amount, were conducted by Hoagland and others in the early years of the previous century (Hoagland and Snyder 1933).

In the middle of the last century many fertilization studies under greenhouse conditions were conducted. In most cases the plants were grown directly in local soil or in containers filled with highly fertile soil imported from other areas. In Japan (Masui *et al*. 1960), a study with muskmelon plants grown in 45 l boxes and supplied with nine combinations of nitrogen and phosphorus and a constant level of potassium, revealed that under the experimental conditions increasing nitrogen levels from 6 to 18 g/plant decreased fruit flesh total soluble solids (TSS) and fruit external appearance. Melons grown in hydroponic systems are even more sensitive to nutrient concentrations. Proper application of NP fertilizers to 'Galia' melons in terms of timing, duration, concentration and source affect not only the yield but also its quality (Ben Oliel and Kafkafi 2002). Another study under hydroponic conditions, in Japan, revealed that sub or super concentrations of the nutrient solution decreased the vegetative growth and the fruit size of 'Amusu' melons (Ikeda *et al*. 1996). These studies demonstrate that in many cases fertilizers can be harmful when used improperly. When supplying mineral nutrients, one has to take in account that muskmelon plants have variable needs at different stages of development. For example, the rate of nitrogen uptake gradually increased before pollination, rapidly increased immediately after pollination and subsequently after 15 days decreased sharply to the same rate as before pollination (Kagohashi *et al*. 1978; Bhella and Wilcox 1985). In order to obtain high quality fruits it was recommended to gradually decrease nutrient supply during the maturation phase and then to completely remove all nutrients about 10 days before harvest (kagohashi *et al*. 1981). In a recent study, where muskmelon were grown hydroponically in plastic bags filled with perlite (inert medium) in a passively ventilated greenhouse, it was found that changing the nitrogen concentration of the fertigation solution, according to predicted nitrogen requirements of the plant during its life cycle, may result an increase in fruit yield (Rodriguez *et al*. 2005). This response was not consistent (only in one out of three seasons) and as much it is another example demonstrating the difficulties in conducting fertilization studies that require many repetitions in order to achieve reliable conclusions. Sometimes, the application of different rates of potassium to greenhouse-grown muskmelons, either to the medium or by foliar spray, do not affect yield but show a potential for improving certain quality traits such as flesh firmness and sweetness, and for decreasing the concentration of the microelements Fe and Mn in the leaves (Demiral and Koseoglu 2005; Lester *et al*. 2005). Adequate potassium supply may also play a roll in enzymatic activities involved in mineral translocation. The effect of different macronutrients (N, P and K) application rates on the accumulation of micronutrients (Fe, Mn, Cu and Zn) was studied in cucumber. The data showed a significant relationship between macronutrient availability and the rate of micronutrient uptake (Moreno *et al*. 2003). Nutrient levels do not necessarily have the same effects even for related species. A Spanish research group demonstrated that macronutrient levels did not affect the content of leaf pigments such as chlorophylls, carotenes and anthocyanin in muskmelon, but did affect their contents in cucumber (Valenzuela *et al*. 1994; Lamrani *et al*. 1996). The level of a mineral element in the nutrition solution does not only affect nutrient uptake of other elements, but may also affect their distribution among the different fractions. For example, the nitrogen level in the nutrient solution affected the distribution of P and Ca in the inorganic, organic, lipidic, proteic, RNA and DNA fractions in cucumber leaves (Valenzuela *et al*. 1992), while NPK levels affected the distribution of P in these same fractions in muskmelon (Valenzuela *et al*. 1996). Nitrogen level and source, significantly affected the uptake and the distribution of both macro- and micronutrients in cucumber fruit tissues (Kotsiras *et al*. 2002). Uptake of nitrogen is a two steps process; absorption and assimilation. Absorption of nitrate by roots and its assimilation by nitrate reductase activity are temperature-dependent and are therefore reduced at low temperatures. However, since this enzyme acts in cucumber and gourd primarily in the leaves, low root zone temperatures did not significantly affect nitrate assimilation (Tachibana 1988). In cucumber, maximal nitrate reductase activity *in vivo* was recorded near the end of the day (Tachibana *et al*. 1991). In cucumber, high K levels resulted in high uptake, translocation and reduction of nitrate in leaves and high translocation of organic nitrogenous compounds (amino acids) to the fruit (Ruiz and Romero 2002).

The chemical and physical properties of the growth medium have a significant effect on nutrient uptake and fruit yield. In cucumber and muskmelon, P and K requirements depended primarily on growth medium composition; generally plants grown in inert volcanic gravel or in sandy media consumed more phosphorus and potassium than those grown in media rich in organic matter (Nerson *et al*. 1997). Cucumbers grown in four artificial substrates had different yields and mineral composition in leaves and fruits (Colla *et al*. 2003). Cucumbers grown in peat responded to high levels of phosphorus and nitrogen fertilizer applications. Fruit yield increased linearly with an increase in superphosphate application rate up to 2 kg/m^2, phosphorus content (in the leaves) up to 0.6% and nitrogen concentration in the nutrient solution up to 175-300 mg/l (Adams and Winsor 1984; Adams *et al*. 1992). In container-grown cucumber, the response to phosphorus nutrition in addition to infection with vesicular-arbuscular mycorrhizal fungi (VAM) was studied. Fruit production was increased by increasing the weekly amount of P from 90 to 360 mg per plant, whereas VAM enhanced the vegetative growth but did not affect the reproductive phase later on (Trimble and Knowles 1995). The presence of certain chemicals with allelopathic effects may reduce nutrient uptake. Lyu and Blum (1990), using a split-root system, found that ferulic acid decreased P, K and water absorption in cucumber seedlings. Uptake of water and nutrient elements in hydroponicaly-grown cucumbers was also influenced by day and night differences and diurnal variations of light and temperature. Uptake increased to a maximum during the brightest hours of the day when the solar radiation and the air temperature are highest and the oxygen content in the nutrient solution was lowest (Gislerod and Adams 1983; Masuda *et al*. 1990). Application of any nutrient element must take into account not only the amount, but also the ionic forms that are available in the root zone. It has been well documented that in cucurbits, in most cases vegetative and reproductive growth is enhanced when nitrogen is supplied as nitrate rather than as ammonium (Barker and Maynard 1972; Wu 1979; Hanada 1980; Masui *et al*. 1982; Alan 1989; Heuer 1991; Simonne *et al*. 1992; Lee *et al*. 1993). Lindt and Feller (1987) analyzed the exudates of xylem and phloem in cucumber plants fertilized with nitrate and ammonium and found that nitrate was directly transported from the roots to the shoot. In contrast, ammonium had to be converted to an organic form (an energy demanding step) before it could translocated, which resulted in decreased growth. In cucumber, this phenomenon was found to be varietal-dependent, both in the composition of xylem exudates and in vegetative growth (Zornoza *et al*. 1996). Another advantage of nitrate over ammonium as a nitrogen source is due to the lower uptake of Na and Cl and higher absorption of K. Ammonium as a nitrogen source in muskmelon and cucumber nutrition, decreased potassium uptake and root hydraulic conductivity, and increased the net rate of sodium and chloride influx into the sensitive leaf blades (Martinez and Cerda 1989; Adler and Wilcox 1995; Adler *et al*. 1996). Ammonia in the nutrient solution may be toxic to cucumber plants. This was expressed as leaf chlorosis, and by a general decrease in assimilation and transpiration activities (Schenk and Wehrmann 1979). A series of studies in Japan revealed that the main factor responsible for limiting growth when N was applied in ammonium form in cucumber and twelve other crops was the change of pH in the root zone (Moritsugu *et al*. 1983). It was found that by maintaining a constant pH there was no difference in plant growth between nitrate or ammonium sources. Adequate calcium availability during fruit development has positive effects on storage ability, vitamin C content and firmness (Bangerth 1979). In muskmelon, most of the calcium accumulation in the fruit occurs early and probably played an important role in preventing flesh-watercore disorders (Bernadac *et al*. 1996). In 'Andesu' melon calcium exclusion accelerated fruit softening, alcoholic fermentation and ethylene evolution, and decreased sucrose accumulation (Nishizawa *et al*. 2004). The form of calcium applied to greenhouse-grown muskmelon had a significant effect on post-harvest characters of the fruit. Fertilization by calcium chloride (as compared to calcium carbonate) increased and enhanced respiration and the production of ethylene and decreased shelf life (Mallick *et al*. 1984). In order to maximize fruit production in cucumber the nutrient solution has to contain the proper proportion of required elements. The best calcium/potassium and ammonium/nitrate ratios were found to be 0.75 and 0.20, respectively (Sarro *et al*. 1994).

ORGANIC NUTRITION

Natural nutrition of plants from non-synthetic sources is made available as a result of the decomposition activities of microflora and higher organisms in the soil. The rate of these processes is dependent upon environmental conditions and generally is of long time nature. Man has learned to use organic residues as a nutrient supply from the earliest days of agriculture and it is the main source of crop nutrition and physical soil amendment in sustainable and organic agriculture to date. A central concept in managing organic agroecosystems is to increase fertility by adding organic matter (like composts) to the soil rather than to supply nutrients directly to the plants. Rosen and Allan (2007) recently summarized the advantages of organic nutrition in crop production and in maintaining soil quality. In the same workshop, NPK sources and management regimes in organic production were widely discussed (Gaskell and Smith 2007; Mikkelsen 2007; Nelson and Janke 2007). The major limiting factor in organic fertilization is that this type of nutrition is indirect and not immediately available like inorganic fertilizers. In order to be beneficial, most organic nutrient sources must be applied well before the crop is planted. On the other hand, the main advantage of organic nutrition is its positive contribution to environmental conservation and prevention of soil and water pollution.

Cucurbits, like other crops utilize organic nutrient sources in many different agro-systems. In muskmelon, green manure and animal manure were very effective in producing high biomass and fruit yields, and legume green manure was found to be a much better nitrogen source than wheat green manure (Singogo *et al*. 1996).

FERTILIZATION UNDER ENVIRONMENTAL STRESSES

Generally, crops are grown under less than optimal conditions and where it is possible to define the environmental limits we are talking about stresses. One of the major stresses for agricultural crops is salinity in the root-zone; either from saline soil or from saline water used for irrigation (Grattan and Grieve 1999). Crop performance may be adversely affected by salinity-induced nutritional disorders. Salinity limits vegetative and reproductive growth and decreases yield in accordance to its severity. Salinity affects almost every physiological function and can be identified and evaluated in the field as well as at the cellular level in laboratory tissue culture systems (Stavarek and Rains 1984). Cucumbers grown hydroponically in a Nutrient Film Technique (NFT) under saline conditions were unable to uptake sufficient water and calcium, resulting in a significant reduction of dry matter accumulation and translocation to the upper shoot and fruits (Ho and Adams 1994). In cucumber and muskmelon it was found, that calcium nitrate can partially mitigate the adverse effects of saline water (NaCl) on both fruit yield and whole plant biomass (Kaya and Higgs 2002; Kaya *et al*. 2003). In muskmelons grown hydroponically, nitrate fertilization reduced NaCl stress by reducing Na influx and transport to the sensitive leaf blade. On the other hand, fertilization with ammonium decreased potassium uptake and increased the net rate of sodium influx and its damage to sensitive organs (Adler and Wilcox 1995). The efficiency of nutrient uptake under salinity is often cultivar dependent. In a study using ten watermelon cultivars, large differences in macro and micronutrient content among cultivars were reported (Lopez-Cantarero *et al.* 1992). In the past decade much effort has been put into studying the potential benefits of grafting vegetables crops. Melon plants grafted onto a squash rootstock had higher yields and some better physical qualities, such as fruit firmness, than ungrafted control plants under nutrition with saline solutions (Colla *et al.* 2006). It was assumed that grafted plants developed various mechanisms to avoid the physiological damage caused by the excessive accumulation of salts in the leaves (Romero *et al.* 1997). Despite the fact that grafted melons had higher yields than ungrafted controls, only slight differences in macronutrient concentrations were observed in the leaves (Ruiz *et al.* 1997). Another study demonstrated that grafted melon plants on squash rootstocks exhibited lower concentrations of sodium in their leaves than ungrafted controls (Edelstein *et al.* 2005). Shortages of fresh water for irrigation in large semi-arid areas had lead to the increasing use of effluent in agriculture over the past decade. This growing trend has raised a number of new issues such as the validity of established fertilization recommendations. Effluent sources are extremely variable and therefore their nutrient content can vary widely. In Israel, effluent contains in most cases 20-40 mg/l of NH_4-N and very low levels of other plant nutrients (Edelstein *et al.* 2007; Nerson *et al.* 2008). Effluent water is rich in organic matter, microorganisms and heavy metal ions, all of which may influence root nutrient uptake and subsequent plant development. High tolerance to heavy metal toxicity could rely either on reduced uptake or increased plant internal compartmentalization, which is manifested by an interaction between a genotype and its environment. The growing application of molecular genetic technologies has led to increased understanding of mechanisms of heavy metal tolerance/accumulation in plants and, subsequently, many transgenic plants with increased heavy metal resistance, as well as increased uptake of heavy metals, have been developed for the purpose of phytoremediation (Karenlampi *et al.* 2000; Rathinasabapathi 2000; Pilon-Smits and Pilon 2002: Tong *et al.* 2004; Yang *et al.* 2005). However, to date, there are no significant efforts in using these tools to improve heavy metal tolerance of vegetable crops for better performance under contaminated areas. High concentrations of heavy metals in the root zone inhibit the uptake of calcium, a nutrient which has an important role in fruit development of cucumber and melon (Englekes *et al.* 1990; Bernadac *et al.* 1996; Nishizawa *et al.* 2004). Calcium deficiency may also affect translocation of auxins in squash seedlings (Allan and Rubery 1991), cause early yellowing of leaves in cucumber (Boons-Ruijzenaars 1987) and increase sensitivity to fusarium-wilt in melons (Spiegel *et al.* 1987). Lead and cadmium ions were found to inhibit absorption of potassium, calcium and iron (Burzynski 1987). Excess heavy metal levels often cause toxicities, like the case of high boron concentrations in the nutrient solution of melon (Edelstein *et al.* 2005). Interruption of nutrient uptake by effluent irrigation may also be due to its effect on soil pH (Romera *et al.* 1992). Effluents may also disturb the positive symbiotic relationships between plant roots and the soil microflora which often have a beneficial role in crop growth (Valentine *et al.* 2001). It is reasonable to assume that different cucurbit species will have different sensitivities to irrigation with low-quality water, as differences were recorded even at the cultivar level of the same species (Sanchez *et al.* 1990).

Pests, diseases and physiological disorders are common limiting factors in cucurbit crops and fertilization can influence the effects of these stresses. Nitrogen (particularly nitrate rather than ammonium) and calcium were found to reduce nematode and fusarium wilt damage in muskmelon seedlings (Spiegel and Netzer 1984; Spiegel *et al.* 1987). High calcium concentrations in the nutrient solution, was also effective in reducing black rot disease caused by *Didymella bryoniae* in cucumber (Steekelenburg and van Welles 1988). Another fungus disease, downy mildew in muskmelon, increased significantly when a dilute nutrition solution was applied and decreased when enriched with phosphorus or nitrogen (Bains and Jhooty 1978). In cucumber, powdery mildew colonies were larger and had more conidiophores on plants grown under slight or moderate shortages of NPK than on controls (grown on complete nutrient solution) or severely stressed plants (Tomesh and Struckmeyer 1979). In contrast, the effects of virus diseases on squash fruit yield reduction was mainly expressed under high NPK fertilization levels (Thomas and McLean 1967). Gray mold, caused by the fungus *Botrytis cinerea* may be a severe disease of greenhouse cucumber. Calcium nitrate or calcium chloride additions to the nutrient solution caused a significant reduction in disease incidence on fruit and stem (Volpin *et al.* 1990). Blossom-end rot is common in watermelons grown in nutrient poor soils, and fertilization, particularly calcium and nitrogen significantly reduced the incidence of this physiological disorder (Cirulli and Ciccarese, 1981; Scott *et al.* 1993). Foliar application of different fertilizer salts was found to be effective in inducing systemic protection to powdery mildew in cucumber and tomato (Reuveni *et al.* 1995; Ehret *et al.* 2002).

Low-intensity solar radiation reduces photosynthetic activity in all plants, but the light source and radiation wave lengths may impose specific stresses on the plant. For example, UV-A and UV-B radiation are detrimental to cucumber seedlings, reducing growth, biomass and flavonoid content (Krizek *et al.* 1997). Despite the fact that high nitrogen levels enhanced cucumber seedling growth, it failed to overcome the stunting effect of UV-B radiation (Hunt and McNeil 1998).

NUTRIENT DEFICIENCY AND TOXICITY

Deficient or toxic concentrations of any particular nutrient element in plant organs and tissues result in characteristic visional symptoms of the disorder. Numerous symptoms have been documented in scientific articles as well as in colored picture publications which are useful tools for extension services (Ward 1979; Roorda van Eysinga and Smilde 1981: Adams *et al.* 1992; Blancard *et al.* 1994). Years ago, it became clear that cucumber plants are sensitive both to nutrient deficiencies and toxicities and general recommendations for applying fertilizers diffusely, along the growing season, were proposed (Miller *et al.* 1958). Excess nitrogen fertilizer levels enhanced fruit cavity formation in cucumber (Elkner 1982). Watermelon, especially watermelon grafted on bottle gourd, that were grown in soil rich in potassium and calcium had difficulty absorbing magnesium and the morphological symptoms expressed were irregular blackish brown spots on middle leaves ("Hagare" disease) (Arisawa *et al.* 1977). Manganese toxicity in muskmelon is characterized by water-soaked spots, necrotic spots and necrotic lesions and in watermelon by blackish lesions along the leaves veins. These symptoms often appeared in acidic soils or when excess levels of manganese were in the nutrient solution but may be prevented by liming, increasing the magnesium dose in the fertilizer "cocktail" or changing the nitrogen source from nitrate to ammonium (Elamin and Wilcox 1986a, 1986b, 1986c). In the past decade there has been a growing interest in understanding the effects of access boron concentration on plant functions, particularly due to the increasing use of brackish water which is often rich in boron. Earlier studies focusing on the opposite phenomenon of boron deficiency and the related physiological disorders have been thoroughly reviewed (Dell and Huang 1997). Nutrient deficiencies and toxicities are not only expressed by their morphological symptoms but also by a large range of physiological disorders. For example, calcium deficiency reduced basipetal polar transport of auxins in squash (Allan and Rubery 1991). In cucumber, calcium or potassium deficiency decreased the enzymatic activity of nitrate reductase and other enzymes in the leaves, thus reducing the upward translocation of nitrate and the downward movement of carbohydrates (Matsumoto *et al*. 1980; Kobik-Dobosz 1981; Yamaya *et al*. 1982). On the other hand, calcium deficiency increased alkaline phosphatase activity in cucumber roots (Matsumoto and Yamaya 1981). Calcium starvation increased the soluble carbohydrates in cucumber leaves, probably due to a reduction in translocation ability from source to sink organs (Matsumoto and Teraoka 1980). Calcium deficiency in cucumber may simply be a result of an insufficient level of calcium in the root zone, or may also be due to secondary effects of environmental conditions such as high air humidity or high electrical conductivity (EC) of the nutrition solution (Bakker and Sonneveld 1988).

PERSPECTIVES AND FUTURE FOCUS

The greatest advance of biological sciences in the past decade has been undoubtedly the development of biotechnology. Nevertheless, it seems that biotechnology will not contribute to a significant improvement in mineral nutrition of crops. Screening the focus of gene libraries has not included the genetic improvement of crop efficiency to absorb and utilize nutrients. As biotechnology and genetic engineering are geared by economic forces, it looks like investment in development of crops suitable to stressed environments may be applied to large-scale field crops like wheat and rice but not for vegetable crops. In the near future, vegetable production will probably gradually shift from the open field to protected plastic and glasshouses. Research into plant nutrition will focus on adaptations to new greenhouse technologies. For example, the increasing interest in environment quality will increase the efforts to reduce pollution by excess fertilization through the use of more and more closed and recycled ecosystems. Furthermore, the fast development of a new field of agricultural research – precision agriculture – in the last several years, using modern computer science technologies, will probably improve fertilizer usage and decline the leakage of excess water and soil pollutants. Studies concerning the interactions between nutrient-element application and environmental parameters will still be a main focus for research into plant nutrition in the near future. The main lack of knowledge in vegetable- and particularly cucurbit-crop mineral nutrition lies in the inconvenient feeling of uncertainty. Even though many years of research has provided much knowledge for product decision-making, there are still many reports in the literature of surprising and unpredictable results of fertilizer application. Thus, it looks like the main focus of plant nutrition research the near future will remain in improving the understanding of the interactions between nutrient supply and environmental factors.

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