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Extractable Mg, Fe, Mn, Zn, and Cu from a Peat-based Container Medium Amended with Various Micronutrient Fertilizers

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Abstract. **Extractability (in 1 N NH_4OAc, pH 7.0) of Mg, Fe, Mn, Zn, and Cu from a Canadian peat, perlite, and sand medium amended with 6 commercial micronutrient fertilizer mixes was determined over an 80-week period with semi-weekly leaching. With the exception of Fe from FeDTPA, which dropped rapidly from very high levels to almost zero, and Fe from Esmigran, which was not extractable by NH_4OAc, levels of all 5 elements from most fertilizer sources decreased slightly during the 1st month but then remained rather constant for the remainder of the 18 month experimental period. Extractable Mn, Zn, and Fe were reduced significantly by the superphosphate in Micromax Plus.**

Macronutrients in controlled release fertilizers, as well as micronutrients in micronutrient fertilizer mixes, are used widely in soilless container media because they are not readily leached from the medium (17). The availability over time of N and K from controlled release fertilizers is well documented for soilless horticultural container media (12, 18, 19, 25). Although growth responses of plants in containers have been determined for several types of micronutrient fertilizers (2, 3, 5, 8, 27), no studies on the comparative effectiveness of different micronutrient sources over long periods of time have been performed. The purpose of this study was to compare the relative extractibility over time of Fe, Cu, Mn, Zn, and Mg from several micronutrient sources in a peat-based container medium under controlled environmental conditions.

Methods for determining plant availability of micronutrient cations in soilless media are far from standardized. Plant uptake often is used as a measure of availability of nutrients in a particular medium, but plants do not necessarily take up cations in the same ratio as they are available in the soil (20), nor do they take up micronutrient cations with equal efficiencies (4, 7). Although leachate analysis has been used for some elements in soilless media (29), this method does not account for the large potentially available pool of nutrients retained by the medium against leaching. Where leaching occurs over long periods of time, as in long term crops, this pool of nutrients may be of greater significance to the plants than that which is leachable.

Cations extracted from soils by chemical extractants can be useful predictors of plant available nutrients in the soil (24). Since the best chemical extractant for micronutrient cations in soilless container media had not yet been determined, 1 N NH_4OAc (pH 7.0), which has been widely used on many soil types for extraction of Mg and some micronutrient cations was selected for use in comparing the relative extractabilities of these 5 cations over time (1, 10, 13, 24, 28).

Materials and Methods

A container medium consisting of 4 Canadian peat:2 perlite:1 silica sand (by volume) was amended with one of 6 commercially available micronutrient fertilizer mixes at their recommended rates (Table 1) or was not amended (control). Ten 20-liter polypropylene containers were filled with each of the micronutrient-amended media and placed in a 23° ± 1°C room for incubation. Containers were arranged in a completely randomized design with 10 replicates and were irrigated twice weekly with 500 ml of deionized water, about 200 ml of which leached through each container.

Samples were taken at the beginning of the experiment and biweekly thereafter for the first 2 months, monthly for the next 10 months, and bimonthly for the final 6 months. Cores spanning the entire depth of the growth medium were taken from each container and analyzed separately for extractable Fe, Mn, Zn, Cu, and Mg. Holes in the medium were refilled following sample core removal. Samples were oven dried at 50°C for 24 hr. Ten g of each sample were shaken for 30 min in 50 ml of 1 N NH_4OAc (pH 7.0) at 280 OPM (10). Clear, particle-free filtrates were obtained by suction filtration through 2 layers of Whatman No. 1 filter paper, followed by gravity filtration through a single layer of Whatman No. 1 filter paper. After dilution, determinations were made by atomic absorption spectroscopy. The amount of each element extracted per gram of element applied was calculated to compensate for differences in fertilizer analysis and recommended application rates. Nutrient composition of the fertilizer materials (Table 1) and container medium (Table 2) was determined by atomic absorption spectroscopy after H_2SO_4-H_2O_2 digestion (16) of 3 replicate samples of each material. Mean concentrations of each of the elements present in the control containers were subtracted from all treatment data to remove the effects of any inherent fertility in the medium itself. Analysis of variance and mean separation by Waller-Duncan k ratio method were performed on the data for each sampling date. Due to the large number of lines per graph in Fig. 1–5 statistical data are not presented, but all statements in the following text are based on statistically significant ($P < 0.05$) effects.

Results

Zinc. Similar levels of extractable Zn in container media amended with Perk, Micromax, FTE 555, or Esmigran were maintained throughout the 18-month experimental period (Fig.

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Table 1. Composition and application rates for micronutrient fertilizers tested.

Trade name	Cation source	Application rate (g/l)	Composition (%) Fe stated	Fe actual	Mn stated	Mn actual	Zn stated	Zn actual	Cu stated	Cu actual	Mg stated	Mg actual	Manufacturer
Perk	Oxides & sulfates	1.8	9.0	8.8	2.0	1.8	1.0	0.8	0.5	0.7	5.0	10.0	Estech Chem. Co. Chicago, Ill.
Micromax	Sulfates	0.9	12.0	16.0	2.5	2.2	1.0	1.3	0.5	1.1	---	0.3	Sierra Chem. Co. Milpitas, Calif.
Micromax Plus	Sulfates[z]	5.9	1.5	2.8	0.3	3.7	0.1	2.1	0.05	0.18	6.0	10.5	Sierra Chem. Co. Milpitas, Calif.
FTE 555	Fritted oxides	0.07	14.0	30.2	5.0	6.2	5.0	10.6	1.5	2.2	---	0.7	Peters Fert. Co. Allentown, Pa.
Esmigran	Adsorbed on clay	3.0	2.0	3.6	0.5	0.5	1.0	0.9	0.3	0.3	---	3.6	Mallinckrodt St. Louis, Mo.
Fer-A-Gro[y]	Sulfates	1.7	4.0	5.6	3.9	4.3	2.4	3.1	---	0.01	6.7	12.3	Florida East Coast Fert. Co. Homestead, Fla.
Sequestrene													Ciba-Geigy Greensboro, N.C.
330 Fe	$Na_2FeDTPA$	0.082	10.0	10.0	---	---	---	---	---	---	---	---	
Mn	$Na_2MnEDTA$	0.0165	---	---	12.0	11.2	---	---	---	---	---	---	
Zn	$Na_2ZnEDTA$	0.0165	---	---	---	---	14.2	12.0	---	---	---	---	
Cu	$Na_2CuEDTA$	0.0165	---	---	---	---	---	---	13.0	13.6	---	---	

[z] Micromax Plus contains dolomite as a Mg source as well as 0.8% p from superphosphate.

[y] Fer-A-Gro was tested solely as a Mg source.

Table 2. Chemical composition in ppm of 4 Canadian peat:2 perlite:1 sand (by volume) medium used in this experiment.

Material	Fe	Mn	Zn	Cu	Mg
4:2:1 medium	950	200	0	250	700
Canadian peat	900	100	0	300	1000
Perlite	900	500	0	100	200
Sand	1300	0	0	300	400

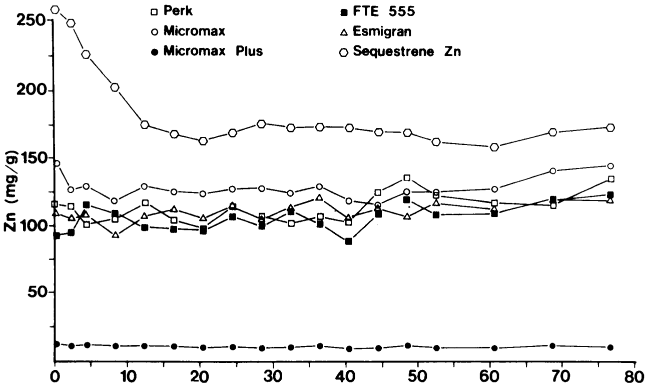

Fig. 1. NH_4OAc — extractable Zn from 6 different micronutrient sources in a peat-based container medium. Data represent mg of extractable Zn per g of Zn applied.

1). Extractable Zn from the Micromax Plus-amended medium was less than one-tenth that of the Micromax-amended medium which contains the same micronutrient sources, but does not contain dolomite or superphosphate. Initially, Sequestrene provided Zn at about twice the level of the other Zn sources. After 12 weeks extractable Zn from this source decreased slightly, but maintained this level for the remainder of the experiment.

Manganese. Extractable Mn levels from Perk, Micromax, FTE 555, and Esmigran were initially similar, but Mn from FTE 555 increased slightly with time (Fig. 2). Initial Mn levels in media amended with Micromax Plus averaged about one-tenth that of Micromax, but extractable Mn from this treatment decreased to almost zero after 76 weeks. Chelated Mn provided very high levels of extractable Mn throughout the experiment.

Iron. Iron from all sources but Micromax decreased during the 18-month period, and all Fe levels except initial chelated Fe were substantially lower than those for Mn and Zn (Fig. 3). Extractable Fe from Perk, Micromax Plus, and FTE 555 amended media dropped substantially during the first 2 weeks, but maintained comparable levels thereafter. Esmigran provided essentially no Fe initially and actually resulted in less extractable Fe than the control containers after 12 weeks. Chelated Fe initially provided high levels of extractable Fe, but these levels dropped rapidly so that after 40 weeks the control containers had greater amounts of extractable Fe than the chelate treatment.

Copper. Copper levels from all sources decreased somewhat

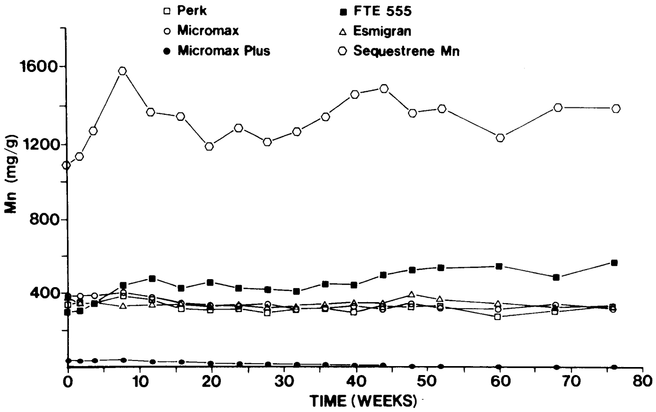

Fig. 2. NH_4OAc — extractable Mn from 6 different micronutrient sources in a peat-based container medium. Data represent mg of extractable Mn per g of Mn applied.

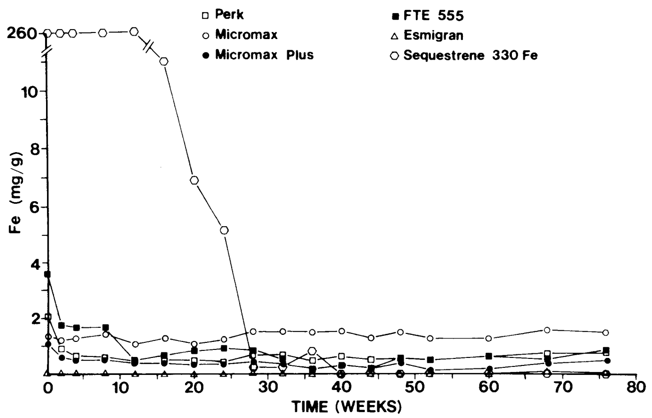

Fig. 3. NH_4OAc — extractable Fe from 6 different micronutrient sources in a peat-based container medium. Data represent mg of extractable Fe per g of Fe applied.

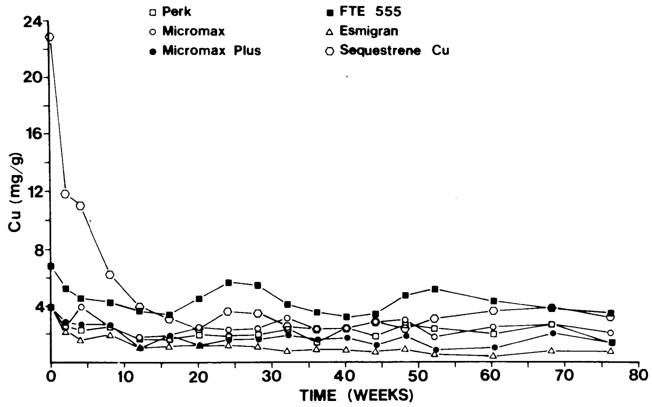

Fig. 4. NH_4OAc — extractable Cu from 6 different micronutrient sources in a peat-based container medium. Data represent mg of extractable Cu per g of Cu applied.

during the first 2 weeks of the experiment, but Cu from Cu-EDTA continued to drop until about 8 weeks (Fig. 4). Extractable Cu levels in all treatments remained relatively constant thereafter.

Magnesium. Only 3 fertilizers containing Mg were tested: Perk, Micromax Plus, and Fer-A-Gro. Extractable Mg levels from Perk remained quite constant throughout the experiment, but at extremely low levels compared to Micromax Plus or Fer-A-Gro (Fig. 5).

pH. Container medium pH was monitored monthly and averaged 4.1 initially for treatments other than Micromax Plus and gradually increased to about 4.2. Media amended with dolomite-containing Micromax Plus had an initial pH of 4.1 and final pH of 6.1.

Discussion

Zinc. Although Zn solubility reportedly is not reduced by superphosphate (11, 21), the extremely low levels of extractable Zn in the Micromax Plus medium suggests that insoluble Zn phosphates were formed at pH 7.0 during extraction, if not in the medium at pH 4.1. In a separate experiment, we determined that $ZnSO_4$ and triple superphosphate remained in solution at pH 4.1, but precipitated out at pH 5.6 or above. Since it is common practice to lime container media to pH 5.5–6.5, the results obtained here by extraction at pH 7.0 should reflect the plant availability of Zn from micronutrient fertilizers in superphosphate-amended media under typical growing pH conditions.

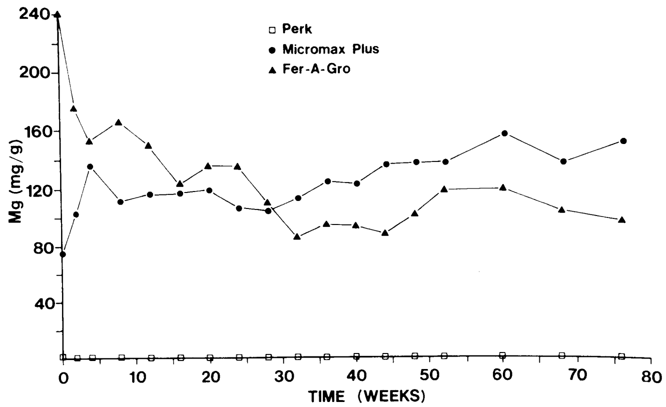

Fig. 5. NH_4OAc — extractable Mg from 3 different micronutrient sources in a peat-based container medium. Data represent mg of extractable Mg per g of Mg applied.

Once adsorbed to the medium, or complexed with organic matter, Zn appeared to be relatively unaffected by leaching. With the exception of chelated Zn, all Zn sources tested were about equally effective in supplying Zn. Differences in manufacturers' recommended application rates, however, mean that some materials, such as Esmigran, supply up to 4 times the amount of Zn as FTE 555. The initial drop in extractable Zn from ZnEDTA probably is due to leaching of this soluble form. Zn levels from chelate stabilized after about 12 weeks, suggesting that Zn was no longer chelated, and hence, water soluble, but was complexed with organic matter in the medium.

Manganese. Although all materials but the EDTA chelate supplied Mn equally effectively in this system, differences in recommended application rates account for about a 6-fold difference in actual soil levels of Mn between materials such as Perk and FTE 555. The presence of superphosphate, however, reduced the extractability of the applied Mn in Micromax Plus by about 90%, presumably due to the formation of insoluble phosphates (9, 22) at pH 7.0. Precipitation of Mn with superphosphate was determined experimentally to occur at pH 6.2–6.5, which is within the typical pH range for container media.

Extracts of the Mn chelate-amended medium consistently yielded more Mn than was applied. A separate experiment showed that 1 N NH_4OAc at pH 7.0, when combined with the levels of EDTA present in the soil from this treatment, was capable of extracting Mn from the medium itself in quantities consistent with the data shown in Fig. 2. However, Mn was not leached from the MnEDTA treated medium during this experiment because at pH 4.1, as in this medium, the Mn-EDTA complex is unstable and Mn exists largely as the free cation (23).

Iron. During the entire 18 months, extractable Fe from all sources except Sequestrene was rather low. The presence of superphosphate has been reported to render applied Fe insoluble (6, 14), but Fe levels were not significantly lower in the superphosphate containing medium than in media lacking this material. Iron can form strong complexes with organic matter in media and may not be extractable in such instances with NH_4OAc (26). Also, the solubility of Fe at the extractant pH (7.0) is very low compared to its solubility at pH 4.1 (15).

The very low initial extractable Fe levels from Esmigran and subsequent levels lower than in control containers were explained by an additional experiment in which it was determined that only 0.3 μg of 72 μg of Fe in Esmigran were extractable with water or NH_4OAc. When a 5 ppm Fe solution was passed through a column containing 2 g of Esmigran, only 0.18 ppm of Fe leached through it, but 0.67 ppm of Mn were released from the clay particles and were measured in the leachate. Similarly, when a suspension in water of the unamended medium which contained 0.3 ppm NH_4OAc-extractable Fe was poured through an Esmigran column, 1.8 ppm of Fe were removed from the suspension by the clay particles. Thus the affinity of this clay for Fe is much greater than that of the medium, resulting in a net loss of extractable Fe from the medium when Esmigran is added.

Chelated Fe initially resulted in high levels of extractable Fe in the medium, but Fe levels dropped rapidly due to leaching, and after 40 weeks, the chelate-amended medium had less extractable Fe than control media. This phenomenon can be explained by the stronger affinity of both EDTA (from the Cu, Mn, and Zn chelates) and DTPA (from the Fe chelate) for Fe than for Cu, Zn, and Mn at pH 7.0 or less (23). Iron from the medium itself replaced Cu, Mn, and Zn from their respective EDTA complexes and was then leached from the containers by irrigation. Therefore, applications of any non-Fe chelate to such a medium could result in a net loss of Fe from the system due to the stronger affinities of common chelating agents for Fe than for other metals at the relatively low pH of such media.

Copper. Copper levels from all sources but CuEDTA were relatively constant throughout the 18-month period. The rather low extractable proportion of the applied Cu from most materials probably is due to the strong complexation of organic matter with Cu (26). The presence of superphosphate had little effect on extractable Cu levels in this medium. Extractable Cu from CuEDTA decreased initially as soluble chelates were leached from the medium, but some of the EDTA probably released its Cu and bound to Fe in the medium while the released Cu complexed with organic matter. All of the Cu sources tested appeared to be equally effective in supply Cu in this type of medium, but again, recommended rates and percentage of composition vary widely among products, with the result that commercial micronutrient mixes applied as directed do not supply the same amounts of Cu to the medium.

Magnesium. Perk was a much less effective Mg source than was Micromax Plus, which contains dolomite or Fer-A-Gro, which utilizes the sulfate form of Mg. Perhaps this difference is due to the insolubility of MgO and leaching of $MgSO_4$ contained in Perk. Extractable Mg decreased over time in the Fer-A-Gro amended medium due to leaching. The dolomite in Micromax Plus appears to be the best source of Mg under these conditions.

Conclusions

Zinc, Mn, and Cu can be supplied effectively in acid soilless media by sulfates, oxides, or adsorbed to clay particles. Extractable Zn and Mn levels in the medium used in this study were reduced by about 90% by addition of superphosphates; however, Cu was relatively unaffected by the presence of superphosphate, since it complexes preferentially with organic matter. Of the Fe sources tested, Fe sulfate and oxide were about equally effective in supplying this element. Iron was adsorbed too tightly to the clay in Esmigran to make it a useful Fe source, and the presence of this material in soilless media may result in even the Fe in the medium itself being rendered unextractable. FeDTPA was perhaps the best source of Fe tested, but because this material is soluble, all of the added Fe was leached from the medium after 40 weeks. The effective life of FeDTPA in a peat-based medium is therefore somewhat less than 40 weeks and seems to depend on the amount of leaching during irrigation. Manganese, Zn, and Cu chelates were good sources for these elements, but, because of the stronger affinity of EDTA for Fe, use of these chelates in soilless media may result in less Fe availability. Magnesium was best supplied as dolomite, although leaching of $MgSO_4$ was minimal after 18 months. Apparently MgO was not readily solubilized in the medium.

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Effects of 2% O_2 and Varying Concentrations of CO_2 with or without C_2H_4 on the Storage Performance of Kiwifruit

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Additional index words. *Actinidia chinensis*, controlled atmospheres, physiological disorders, firmness

Abstract. **The storage performance of kiwifruit (*Actinidia chinensis* Planch. 'Hayward') was evaluated during and after storage for up to 24 weeks in 2% O_2 and 0%, 3%, 5%, and 7% CO_2 at 0°C. In addition, the influence of exposure to 0.5 or 1 µl·liter^{-1} C_2H_4 on fruit performance was evaluated. The rate of softening during storage was reduced in proportion to the CO_2 level and was accelerated by C_2H_4. The presence of white core inclusions under controlled atmospheres (CA) plus C_2H_4 was dependent upon the CO_2 concentration. Two other physiological disorders were observed, and their severity was influenced by the combination of elevated CO_2 and C_2H_4. The results suggest that there are 2 types of interactions between CO_2 and C_2H_4, competition and synergism, which occur in kiwifruit during storage.**

CA storage has been shown both experimentally and commercially to extend the shelf life of many horticultural commodities (7, 16). In recent years CA storage of kiwifruit has been successful because it alleviates the softening problem which occurs during storage in air at 0°C (1, 12, 13). For maximum benefit, CA storage of kiwifruit must be established within one week of harvest (2).

Successful CA storage depends upon a number of factors, particularly the levels of CO_2 and C_2H_4 in the storage atmosphere (7, 16). Although Blanpied et al. (4) initially reported that C_2H_4 had no effect during CA storage of apples , Liu (11) subsequently showed that C_2H_4 influenced the rate of softening and loss of acidity. We reported the detrimental effects of C_2H_4 during CA storage of kiwifruit (1). McDonald and Harman (12) confirmed that the benefit of CA is minimized if C_2H_4 is present.

This study was designed to examine the effects of CO_2 at 0%, 3%, 5%, and 7% in conjunction with 2% O_2 on the storage performance of kiwifruit, and also to evaluate the influence of 0.5 or 1.0 µl·liter^{-1} C_2H_4 when combined with the various CA treatments.

Materials and Methods

Kiwifruit 'Hayward' were harvested during the 1980 and 1982 seasons from the same commercial planting in Gridley, Calif., and transported to the Postharvest Pomology Research Facility at the Univ. of California, Davis. To minimize decay during storage, the fruit were dipped in a combination of 600 µl·liter^{-1} sodium orthophenylphenate and 1125 µl·liter^{-1} 2,6-dichloro-4-nitroaniline, adjusted to pH 11.0 (17). The fruit were sorted to eliminate defective or blemished individuals and then cooled overnight at 0°C.

After cooling, fruit either were placed in vented polyethylene bags for air storage in a room with low (<0.015 µl·liter^{-1}) C_2H_4 contamination in the air or in 1.5 m^3 CA storage chambers. The desired CA treatment was attained within 24 hr of harvest by a flow-through system (500 ml·min^{-1}). Storage atmospheres were monitored by gas chromatography and maintained within 5% of the desired level. The 1980–1981 storage test consisted of 4 CA treatments (air, 2% O_2, air + 5% CO_2, and 2% O_2 + 5% CO_2) with or without the addition of 1.0 µl·liter^{-1} C_2H_4. Five CA treatments (air, 2% O_2, 2% O_2 +

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