THE EFFECT OF SOME MEDIA COMPONENTS ON THE MICRONUTRIENT COMPOSITION OF SOME CONTAINER-GROWN PLANTS.

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Colin Bruce Christie
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In 1860 Sachs made the following statement:

"I published the results of experiments which demonstrated that land plants are capable of absorbing their nutritive matters out of watery solutions, without the aid of soil, and that it is possible in this way not only to maintain plants alive and growing for a long period of time, as had long been known, but also to bring about a vigorous increase in their organic substance, and even the production of seed capable of germination."

Julius von Sachs
Lectures on the Physiology of Plants
Claredon Press, Oxford, England. 1887

ABSTRACT

Plants were grown in a range of soilless growing media made from peat, perlite and pumice.

Plant samples and media extracts were analysed by atomic absorption spectrophotometry.

All media components used proved to be sufficiently reactive with respect to micronutrients to modify nutrient levels in plant foliage. This is supported by differences in micronutrient extractability and sorption by media components.

The use of fritted trace elements did not prevent the appearance of Fe chlorosis, but did increase the foliar level of some micronutrients.

The results show some nutritional differences between peats from different sources. Differences in mineral uptake associated with perlite and pumice were also observed. These differences may explain why iron chlorosis may be induced in plants grown in perlite based substrates and not in pumice based substrates.

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Introduction

The omission of soil from the growing medium has generally produced a substrate more satisfactory for plant growth with current cultural practices.

However, observant growers have noted that when a range of soilless media are similarly fertilized and compared they will often yield large differences in plant growth response.

Leaving soil out of the medium has reduced many problems of management,but it has introduced some others that require investigation.

Foliar chlorosis and delayed flowering in some plants may be increased when grown in peat-perlite mixtures, this problem occurs less frequently in peat-sand or peat-pumice mixtures.

The addition of a relatively small proportion of soil to the growing media may reduce the variation in plant growth response observed between different media,and may even prove beneficial in some situations.

Experience on growers' properties suggests the media may be altering the availability of some micronutrients.

CHAPTER 1

LITERATURE REVIEW

Introduction

Within the ornamental horticulture industry there is a growing awareness that alternatives to soil must be found, if container culture is to become a viable proposition.

Increased plant densities with greater flexibility of production and planting season have been achieved in a shift from open ground production to container production. However, with the shift to container production, the well structured natural soil, suitable for open ground use, began to prove unsatisfactory as a growing medium.

Even in well structured soils insufficient large pores exist to allow sufficient drainage from the perched water table created in a shallow container (Hanan and Langhan, 1964; White, 1964; and Spomer, 1974). Well structured soils tend to become compacted during production cycles of a few months to several years. As compaction increases, the water infiltration rate, hydraulic conductivity and air pore all decrease significantly, subsequent plant growth is reduced. (Richards et al, 1964; Morgan,et al, 1966; and Grable and Siemer, 1968).

The most important single factor contributing to the physical deterioration of soil in containers is the high frequency and rate of water application required to sustain rapid plant growth (van Diest, 1962; Bruce-Okine and Lal, 1975).

Fundamental studies to define the precise physical and chemical requirements for optimum g rowth in a growing medium do not appear to have been conducted systematically prior to 1952 when some basic studies were carried out by Deshuses and Duperrex. Prior to this time development of a suitable growing medium had proceeded on a very emperical basis.

(1) Container growing media

Container growing media may be divided arbitarily into four basic types; (a) media based on soil, (b) media based on clay (c) peat-sand media, and (d) synthetics.

(a) Media based on soil

Initially, horticulturists produced soil mixes that were intended to imitate the soil found in a plants natural habitat. This gave rise to an era in which a very large number of different growing media were used (Sanders, 1931).

During the period 1934-39 the John Innes Horticultural Institute made the first attempts to formalise a standard growing media. Two growing media were produced, one for seedlings, and the other for general potting, in which quite a variety of plants would grow successfully. Both John Innes Media (JIP Media) were based on proportions of loam, peat and sand (Lawrence, 1937; Anon. 1941).

Lawrence (1938) suggested that good results could be obtained from a medium of poor physical composition after the addition of extra phosphate, thus the quality of the loam 'was not of first importance if fertilizers were added'. This idea was later rejected. The peat should be relatively undecomposed, being either a sedge or sphagnum type, with a pH greater than 3.5. The sand should be clean and coarse, 60-70% of the particles 1.5 - 3.0 mm in diameter (Lawrence and Newell, 1952). During the period 1946 - 1949 Lawrence came to recognise the importance of a well structured loam. Considerable variability of plant growth in the past could be attributed in part to poor quality loam. In 1954, Pizer and Pearl assessed the quality of suitable loams for JIP media with the intention of reducing the variability of the final product.

A wide and diverse range of plants were grown successfully in JIP media without any additional trace element requirement (Lawrence and Newell, 1952).

The standard JIP media proved unsuitable for calcifuge plants. Alvey (1955) replaced the chalk content of the medium with sulphur. Ericaceous plants grown in this medium produced superior growth and no chlorosis, when compared with growth in a peat-sand medium.

Lloyd (1952) found that the addition of Krilium to soil promoted the development of a more stable crumb structure, with increased soil aeration and water-holding capacity. Increased growth of tomatoes was reported where Krilium was added to soil, compared with unamended soil. However, where Krilium was used as a substitute for peat and sand in the JIP media or as an additive to the JIP media no significant improvement was noted (Lawrence 1953, 1954).

Addition of vermiculite to JIP media improved and stabilised the drainage characteristics of the medium. In contrast, unamended JIP media deteriorated rapidly (Hayes and Simpson, 1958). These observations were confirmed by Maas and Adamson (1972). Adding soil to a growing medium accelerates the decomposition of the organic fraction. This is rapidly followed by the loss of large pore spaces with consequent deterioration due to compaction. Larger Antirrhinum and Salvia plants were produced on the amended media. Flowering also occurred more rapidly in this medium (Hayes and Simpson, 1958).

Poole et al (1968) observed that the growth and grade of Hibiscus and Aralia plants decreased as the proportion of soil in the media increased, which suggests that the presence of soil in the medium is deleterious.

(b) Media based on clay

Fruhstorfer (1953) of Hamburg attempted to develop a standardised growing medium with the following characteristics; a stable crumb structure, relatively free from weed seeds, decomposable organic matter, and bacterial life capable of initiating the break down of structure.

Elimination of the need to disinfect the medium reduced the importance of organic toxins (Rovira and Bowen 1966), Al toxicity (Messing, 1965) and Mn toxicity (Baker, 1957; Messing, 1965; Boyd , 1971). Toxicity arising from any of these factors may occur after heat treatment of soils.

Fruhstorfer specified that Einheitserde (Standard Earth) should be made from equal parts of a montmorillorite based clay (with high base exchange capacity) and peat (Klougart and Olsen, 1969). The combination of these two materials produced a relatively stable crumb structure.

Alternatively,Fruhshorfer (1953) suggested a mixture of clay and sand would produce a similar structure. When Pill and Lambeth (1975) used this medium, an increase in tomato yield was noted as the proportion of clay used in the media increased. This is perhaps surprising as Klougart and Olsen (1969) observed that with increasing clay content the air pore space diminished to an unacceptably low level. If pore space was not limiting growth,then possibly additional nutrients derived from the clay may have contributed to the increased yields.

Maatsch (1952) reported that Einheitserde was being producted in a few centrally located factories and the quality of the medium was regularly checked to ensure it was a satisfactory standard. Manufacture in a small number of factories combined with the use of large uniform deposits of suitable clay and peat ensured consistent and repeatable results (Fruhstorfer, 1953). He predicted a failure for nurserymen who attempted to produce their own medium from non-standardised resources. This is borne out by Allerton's experience. In 1958 Allerton attempted making Einhertserde in England, but found that the clays he used were unsuitable. Genuine Einheitserde compared favourably with JIP media, but the locally produced material did not compare at all well.

A range of plant subjects were grown successfully in Einheitserde and usually proved superior to an ordinary medium (not described). Inferior growth of celery and cauliflower was noted in the Einheitserde (Heydemann, 1952). Hulsmann and Thiele (1953) also reported good growth of a wide range of nursery stock grown in Einheitserde. They noted that during pricking out and potting of plants, firming of the medium in a conventional manner was detrimental to its structure. This reduction in free air space after firming could be undesirable. The maximum of 13% free air space measured in Einheitserde after drainage is considered low, for a container medium (Klougart and Olsen, 1969). Aeration is improved by reducing the proportion of clay added to the peat or by adding pulverised clay instead of granulated material. Only enough clay is added to cover the surface of all the peat particles (requires 50-100kg/m^3). After incorporating lime and gypsum, which are added sparingly to Einheitserde (Sutton, 1958), the free air space may be raised to greater than 20% (Klougart and Olsen, 1969).

Laurie (1930) appears to be one of the earliest researchers to use pure peat as a growing medium, however he did not find it a satisfactory substitute for a soil and manure compost. Similarly Deshusses and Duperrex (1952) observed poor growth of plants in pure peat.

In 1957, Baker suggested using pure peat for the production of acidiphilous plants in California. Woolet and Neiman (1958) have since noted there has been a large increase in the use of pure peat, it has become widely accepted as a useful propagating and growing medium in England and Germany. Puustjarvi (1962) noted exceptional yields of tomatoes and cucumber could be achieved when grown in 'almost' pure peat.

Many European growers are using almost pure peat to grow a wide range of plant material e.g. 'cacti, ferns, orchids, conifers, annuals, vegetables, rhododendrons and flower bulbs' (Penningsfeld, 1974). Some pot plant growers are still adding clay to their media prior to use (Boertje and Bik, 1975).

Pure peat has proved to be a useful substrate as it combines desirable physical and chemical characteristics (Puustjarvi, 1962; Stromme and Oydvin, 1966; Pollock, 1971, De Boodt and Verdonck, 1972).

Slade (1959), and later Bates (1974) in comparing New Zealand peats with imported peats, concluded that locally available materials were suitable for use in horticulture, and that the importation of peat was unjustified.

Chroboczeck (1963) was able to distinguish high moor (sphagnum) peat from low moor (sedge) peat as the former required more applied nutrients to achieve optimum results. De Boodt (1965) noted that Azaleas made more growth on white (young sphagnum) peat compared with black (old sphagnum) peat, but related the difference only to physical factors. The nutrient contents of peats have been considered to be of no significance to plants (Puustjarvi, 1966; Gallagher, 1972; Roll-Hansen, 1975).

(c) Peat-Sand Substrates

Sutton (1958) considered that peat-sand mixtures were a natural development from pure sand cultures. Early experiments with pure silica sand as a growing medium were successful with a wide range of ornamentals, but there were disadvantages, sand was considered heavy, moisture retention was low and not cohesive enough for potting on, Laurie (1932).

Beginning around 1928, Laurie (1931) grew annual plants in a range of sand, peat and manure combinations. Growth in the medium containing organic matter was superior to that achieved in pure sand and usually comparable with that achieved in soil. Laurie (1932) concluded that plants could be grown successfully in 1:1 peat-sand mixture if fertilizers were provided periodically. This research was not followed up by other workers for fourteen years. In 1946, Woodcock noted lilies could be propagated and grown successfully in a peat-vermiculite substrate. Azaleas also grew well in a coarse vermiculite-peat medium when fed with liquid nutrients, but where a fine graded vermiculite was used, extensive foliar chlorosis was reported (De Groote, 1952). The fine graded vermiculite may have been a more highly alkaline type (Nelson, 1969) and the free bases may have reduced Fe availability to the plants.

Deshusses and Duperrex (1952), in Switzerland compared a wide range of media combinations based on sand, peat, soil and composts. Some physical and chemical properties of each medium were assessed. Their work showed a correlation between growth and total porosity and between growth and proportion of capillary and non capillary porosity. They concluded that a wide range of plants could be grown satisfactorily for periods up to 2 years in a mixture of fibrous and granular peats, if 5-7% calcareous riversand was added.

In Holland, Hartman-Droge (1954) compared four soil based composts, but was unable to show a connection between physical properties of the media and growth of cyclamen. Lack of uniformity between different media components may have obscured any relationship.

In 1941 the research programme that led to the development of the (U.C. Mix) University of California Mix was initiated.

The object was to develop a uniform reproducible growing medium that would suit a wide range of plants, but lacked loam, turf composting and a high labour input (Baker, 1957).

Early experiments were conducted with fine sandy loam mixed with horse manure. Peat, soon replaced the manure as excessive salinity from dung had been a problem (Baker, 1948). After 1950, fine sand replaced the sandy loam component, this removed a toxicity previously observed after steam disinfection of the medium (Baker, 1957).

Baker (1957) suggested that media components should be of low fertility and not contributed nutrients to plants. If a media component were contributing nutrients it becomes more difficult to assess the nutrient status of the media with complete reliability (unless the magnitude and rate of supply are known). In contrast, if a media were completely inert, thus of nil fertility, then it would be a much simpler operation to determine the optimum nutrient requirements to be added, to achieve optimal growth rates.

Finally, after consideration of the importance of each media component, five media were formulated based on fine sand or peat alone or combinations of these materials (Baker, 1957).

The fine sand suitable for use in U.C. Mix should have a size range 0.05-0.5mm diameter and the percentage coarse sand greater than 0.5mm should not exceed 12-15%. The silt and clay fractions together should not exceed 15%. In California large areas of suitable soils, very high in fine sand, that fit these specifications have proved very satisfactory for use in U.C. mixes.

For the organic medium component, sphagnum peat is preferred, but Baker and many others have suggested that sawdust, woodshavings, ground bark, rice hulls and coconut fibre may be substituted in whole or in part. To lower the cost of production growers may be forced to use increasing quantities of peat substitutes available as industrial byproducts (Rigby, 1963 ; Bosley, 1967; Einert, 1972; Crossley, 1973; Cappaert et al, 1974; Gartner et al, 1974; and Reynolds, 1974).

When Sutton (1959) compared the JIP media with the U.C. Mix, the JIP media did not produce significantly higher yields, except when compared with U.C. Mix E (pure peat). Fresh weights decreased when clay was added to a peat-sand substrate to make Dempsters (1958) Mix.

In 1960 systematic experiments were begun at the Glasshouse Crops Research Institute to ascertain the suitability of loam substitutes in the basic JIP media. Results indicated that peat-vermiculite followed closely by peat-sand combinations were equal or superior to loam-based media (Bunt, 1960).

Replacement of the fine sand of the U.C. Mix has occurred in areas where suitable sands are unavailable, substituting for it a more readily available local resource (Anon. 1961).

In 1965 the Cornell Peat-Lite Mixes were formalized by Sheldrake and Boodley (1966). These were made from equal parts of peat and vermiculite or peat and perlite, they were recommended for short term container production.

Vermiculite produced in the U.S.A. is not usually alkaline (Nelson, 1969) as is the Indian or South African material available in New Zealand Carpenter (1975). The high basicity (pH 9) resulting from release of K, Ca + Mg (Marshall and McDowell, 1965) followed by a rapid structural collapse after frequent irrigation has restricted the horticultural use of exfoliated vermiculite in New Zealand. Dunham (1967) noted that K from vermiculite was plant available. Later, Boodley and Sheldrake (1970) reported that significant amounts of K were still being released after a period of two years.

Mansell et al, (1968) observed increased growth of turnip in a vermiculite medium relative to perlite medium or combinations of each material. The increased growth was attributed to less moisture stress on the vermiculite compared with perlite. This explanation does not appear entirely satisfactory as 20 day-old plants in 10cm pots with daily watering would not be expected to exhibit water stressing. Additional nutrients from the vermiculite may have increased growth or a toxic factor arising from the perlite may have depressed growth, but these were not considered by the authors. Similar results were noted by Smoliak and Johnston (1969) with grasses. The maximum growth was observed in vermiculite, next best medium was sand and the poorest was perlite.

Morrison (1956) proposed using perlite as a medium for plant growth. In 1960 Morrison et al investigated the physical and chemical properties of perlite. Their work shows perlite has very low levels of available macro nutrients and good physical characteristics. Only slightly less growth of cress (Lepidium sp.) was observed in a perlite medium fortified with nutrients compared with a 'good potting soil'. When a balanced fertilizer was used, no nutrient deficiencies were observed in short term cropping.

Wilson and Tunny (1965) have reported that perlite as a substrate has some defects; it may cause a general depression in growth coupled with increased deformity of some seedling plants and it has a limited capacity to supply water to rapidly transpiring plants due to low hydraulic conductivity. Jackson (1974) found the hydraulic conductivity of perlite was higher than that of a sandy loam for equal water deficits which suggests this factor is unlikely to be growth limiting. Penningsfeld (1974) also considered the available water from perlite based media was adequate for satisfactory plant growth.

Nuffer (1963) recommended using peat/perlite combinations as container substrates. Since this time perlite has been employed extensively as substrate amendment in many parts of the world, with considerable success (Sokratova, 1965; Sheldrake and Boodley, 1966; Poole et al, 1968; Knavel, 1969; de Boodt and Verdonck, 1971; Angeliev, 1972; Baker, 1972; Beel, 1974;

Patel and Tinga, 1974; Gogue and Sanderson, 1975).

A phytotoxic response of lemons and beans was noted by Erickson and Wedding (1958) when grown in peat-perlite. Similarly Poole and Conover (1973) observed increased foliar necrosis of a Cordyline cultivar when the substrate was amended with perlite.

Good yields have been secured from some crops grown in pure perlite Jennes (1966), Morgan (1972 and Gezi (1974).

However Morrison's original observation of general yield depression, has been observed frequently where pure perlite was the plant growth substrate (de Boodt, 1965; Sokratova, 1965; Mansell et al, 1968; Smoliak and Johnston, 1969; Adamson and Maas, 1971; Angeliev, 1972; and Baikova and Vendilo, 1972).

Kays et al (1974) have reported that where root growth is impeded by a physical barrier then production of ethylene gas is stimulated. Endogenous ethylene may also be produced following abrasion of plant tissue on the siliceous perlite particles. These two factors combined may explain the cotyledon lesions and abnormal seedling distortion observed by Wilson and Tunny (1965).

Variation in plant growth response in a perlite-based substrate appears to concur with Barnett's (1959) report that no two deposits of perlite ore yield products with identical physical characteristics. The chemical composition and characteristics may be equally variable.

Pumice has been used as a growing medium for many years, but literature detailing its properties and use is very scanty.

McIlrath, (1950) has successfully raised tomatoes on a pumice substrate in Iowa and in 1959, Matthews considered New Zealand pumice would be suitable for use in horticulture. A pumice medium has proved satisfactory as a supporting substrate for a range of plants (Bik et al, 1960; Puzzilli, 1963; Esser, 1970; and Cowan, 1973).

Baker, whilst in New Zealand suggested growers might use pumice as a substitute for perlite when lightweight U.C. type substrates were required (Anon. 1961). Criley and Watanabe (1974) did not observe any differences in Chrysanthemum growth upon media of peat/pumice or soil/peat/pumice.

In New Zealand, the most often used substrate combinations are peat/perlite and peat/pumice as the components are available from inexpensive, supposedly uniform sources (Bates, 1973; 1974; Baumgart, 1954; Thompson and Reed, 1954).

(d) Synthetic Substrates

In Europe an extruded rock wool infiltrated with a phenolic resin is being used as a plant substitute. This material is available in cube shaped pieces and has proved useful as a propagating and growing medium when fed via the nutrifilm technique (Huijis and Verwer, 1971; Verwer, 1975).

Synthetic foam plastic materials are being used as substitute amendments. Polyurethane foam, improves substrate water holding capacity, produces higher temperatures around roots and also has a relatively low weight. Plants may be grown directly in polyurethane foam with nutrients incorporated into the porous matrix during manufacture.

Polystyrene chips are suitable as a substrate amendment but not for use alone, on account of their very low water holding capacity (Cook, 1971; de Boodt and Verdonck, 1971; Werminghausen, 1972).

Poole (1969) and later Verwer (1975) report that in the U.S.A. a medium (BR8) manufactured from woodpulp and a synthetic resin has been used with success. Nutrients may be added during processing and plants are grown directly in BR8 blocks as they maybe with rockwool and polyurethane foam.

(2) The ideal substrate

The medium has some functions that must be satisfied in order to allow optimal growth in the substrate. Most crops derive anchorage, moisture and mineral nutrients from the medium. These functions are the same for plants growing in a field or in a container. Bunt (1961) suggests the use of containers changes the physical relation between root and substrate in the following ways:
(i) the small volume of the pot leads to a high root concentration with consequent demands for high rate of oxygen supply and carbon dioxide removal, (ii) the large quantity of water required to sustain the relatively high growth rates observed under glass, must be available within a restricted volume of growing medium, (iii) the shallow depth of the container with its low tension head results in impeded drainage with increased risk of water-logging, (iv) the high frequency of watering renders the substrate more liable to leaching.

Perhaps one of the most important features of a good growing medium is its stability, and the most significant factor that contributes to instability is the high frequency of watering. The frequent filling of pore spaces with water may lead to a loss of structure. Collapse of structure and consequent redistribution of material will lead to a loss of pore space which will alter characteristics of the medium.

The ideal substrate should be designed with the intention of providing the optimal conditions in the root zone for plant growth. However,much of the work conducted in the past has been of an emperical nature with the plant considered secondary to the substrate, only an enlightened few have given plants their due weighting.

The physical and chemical parameters that describe a medium suitable for container culture will now be considered.

(a) Physical Characteristics

(i) Infiltration capacity

The importance of infiltration capacity is dependent on the method of irrigation. If overhead watering is used, application rates in excess of 2.5cm/hr are often achieved, and relatively high infiltration rates are required to allow entry of water into the medium. Where containers are not completely filled with medium or sub-irrigation is practiced, lower infiltration rates are tolerable. The infiltration rate for natural soil is approximately 5mm/hr (Richards et al, 1964). This is usually inadequate with current production practices. Furata (1969) suggests that an infiltration rate in excess of 2.5cm/hr is required for efficient water use in containers.

(ii) Hydraulic conductivity

Hydraulic conductivity of an unamended soil may also be approximately 5mm/hr (Richards et al, 1964). It is desirable that a container growing media has a hydraulic conductivity at least twice the infiltration rate (Furata, 1969). This allows the moisture tension to rapidly return to 'container capacity' (White, 1964) after irrigation,thus reducing waterlogging and poor aeration which may be a problem in a container with its low tension head (Bunt, 1972). Inadequate drainage may be one of the most important factors affecting the availability of nutrients (Hodgson, 1963; Rowe and Beardsell; 1973).

(iii) Easily available water

Significance of this factor is dependent on the interval between irrigations. Regular irrigation or the use of capillary beds reduces the need for large moisture reserves in the container during the production period,but maybe of more importance to consumer.

The pore size distribution fundamentally control the air/water volume ration, at any given moisture tension in the medium (Bik, 1973). Moisture available in peat soils may have a pF range 1.7-2.0 at field capacity. In containers, with their perched water tables pF values of 1.5 or less may exist at container capacity (Kuntze, 1972).

It is well known that energy is expended during moisture uptake, hence it is important that water stored in the medium is freely available at as low an energy status as possible, considering at the same time that enough air must be present in the pores of the medium in the root zone to permit normal respiratory processes (De Boodt and Verdonck, 1972). Richards et al (1964) in California has suggested that moisture was readily available between 0-30cb tension.

In Europe, the easily available water is considered to be that released between 10-50cm (H_2O) tension, and good substrate released 25-75% of its total available water in this range (De Boodt and Verdonck, 1972).

Water buffering capacity is that water available between 50-100 cm (H_2O) tension and should be regarded as a moisture reserve for periods of intense transpiration. Richards et al (1964 have estimated that 4-5% of the total water should be available in this tension range.

(iv) Aeration

The balance of capillary and non capillary pores in the medium is determined largely by the aggregate size and shape, this ratio determines the substrates air-water relationships.

In 1959 Flocker et al showed that, for optimal establishment and growth of tomatoes in three soil types, 30% air space was required. In contrast Bunt's (1961) work showed that for tomatoes the critical air space was 5% for a loam and 25% for sand. For optimal plant growth, De Boodt (1965) considered that within the substrate there should be 20% air, and at the same time 20-30% easily available water.

Grable and Siemer (1968) showed that the relationship between air porosity and root growth was different for each aggregate size distribution and bulk density. For soils of highest bulk density, the critical air space was 11-14%, which increased with coarser texture or larger aggregates up to 40% air space.

Arnold Bik (1973) suggests that some of the disparity in their values may be accounted for by differing rates of gas diffusion in the medium.

Letey et al (1966) found root growth of turf grass ceased when the oxygen diffusion rate was less than 0.15 $\mu g\ cm^{-2} min^{-1}$ and less than 0.2 $\mu g\ cm^{-2} min^{-1}$ for sunflower (Letey et al, 1962). Hence an oxygen diffusion rate of less than 0.2 $\mu g\ cm^{-2} min^{-1}$ would be considered suboptimal for some dicotyledonous plants.

Bik (1973) estimated the critical air content of soil, based on Currie's (1961) formula for porosity, the values attained were lower than expected. As the result, Bik concluded that the oxygen diffusion rate was a better index of soil aeration than soil air content, but 'a critical air content of 20% would be unexpected to lead to any grave misjudgement'.

Puustjarvi (1974) suggested the minimum air space in the media of a rapidly growing crop should not be less than 45-50%. With this air-space, gas diffusion to and from the roots may be fairly rapid, thus ensuring the partial pressure ratio of $CO2/O_2$ is relatively low. The air capacity of media in non porous containers is more important during the periods of low evapotranspiration in winter according to Bunt and Kulweic (1971) as water loss from non porous containers may be only half of that from a porous container. Hence non porous containers tend to remain 'wetter', with fewer air filled pores than porous containers. Reduced growth and regeneration of roots under these conditions may encourage the establishment of soil borne diseases (Stolzy et al, 1965).

Microbial activity in containers may contribute to oxygen deficiency during periods of high respiration (Penningsfeld, 1974). The reduction in the redoxpotential of the soil may increase the availability of some plant nutrients, particularly trace elements (Rowe and Beardsell, 1974).

Verdonck et al (1974) suggests that the ratio of water to air should be close to unity at between 15-25cm moisture tension in good substrates. Substrates, such as perlite may have too much air in the media or a highly decomposed peat may have too much water in the media. A blend of the two materials would lead to a more optimal water/air ratio at low moisture tensions.

(v) Bulk Density

Plant growth may be reduced by increasing the bulk density of the growing medium. This may be due to less available space for media displacement by roots, combined with low oxygen diffusion rates due to compaction (Rickman et al, 1965; Hopkins and Patrick, 1969; and Lowry et al, 1970). Hemsath and Mazurak, (1974) considered that particle packing and trapped water may be preventing root extension growth at high bulk densities.

Media bulk density is an important factor regulating the stability and transportability of container grown plants. Comparatively large plants in light-weight substrates and light-weight pots are easily toppled or blown over. Conversely, large containers filled with a dense medium may be very awkward to handle. Bunt (1974) recommends a bulk density of 0.5g/cm3 for peat-sand substrates which reduces this particular problem.

(vi) Stability

It is important that the characteristics of the growing medium remain stable whilst in use. Media components that differ widely in their size range or relative density are liable to separate out in use (Bates, 1974). Media made from polydisperse or cuboid particles are liable to compact in use. Soil based media are more liable to deteriorate in use as a container medium than soilless substrates (Maas and Adamson, 1972; Mazur et al, 1975).

Significantly less foliage and root growth occurs on compacted media relative to an uncompacted medium (Flocker et al, 1959; Letey et al, 1966; Thurman and Pokorny, 1969). Only minimal shrinkage or contraction of the substrate is permitted in use.

As deterioration of soil structure is largely attributed to the frequency and rate of water application, the use of silane organic polymers in a soil based medium may be an effective means of maintaining water stability of soil aggregates (Koch et al, 1974).

(b) Chemical Characteristics

Chemically, the medium is required to be inert and unreactive. However, paradoxically the medium is also required to stabilise the environment in the root zone.

(i) pH

The availability of many plant nutrients is directly related to the pH of the medium. This relationship has been demonstrated in mineral and organic soils by Truog (1947) and Lucas and Davis (1961) respectively.

The optimum pH range is often 5.5-6.5, but the actual value appears to be of less importance in a peat based medium than in a mineral soil (Baker, 1957; Furata, 1965; Lucas and Knezek, 1972). This may in part be due to the humic acids from the peat increasing the availability and plant uptake of micronutrients(Burk et al, 1932).

Recently, some research workers have applied choline dihydrogen phosphate to a soilless substrate whilst attempting to stabilise pH and reduce the incidence of Fe chlorosis (Wyn-Jones and Scott, 1975).

(ii) Cation exchange capacity

The balance between exchangeable bases and exchangeable acidity in the medium prevents wide fluctuations in media pH by providing some buffering action. This factor is important when nutrient retention is required, particularly if nutrients are applied only once during the growing season as macronutrients (N, P + K) are readily leached from peat-based substrates (Spinks and Pritchett, 1956; Bunt, 1974). In contrast, micronutrients are strongly adsorbed by organic soils (Ellis and Knezek, 1972).

Hence providing macro and micro nutrients at optimal levels for plants at all times has presented some problems.

After the acceptance of the nil fertility medium concept by nurserymen and the introduction of slow release fertilizers, the effects of pH and CEC on macronutrient availability are less important (Oertli and Lunt, 1962). Plants were being grown in a modified hydroponic system in which nutrients could be released from specially prepared fertilizer granules, at known rates over a given period, for review see Hauck and Koshino (1971). Application rates are aimed at providing a plants daily nutrient requirements without any need for retention. Surplus nutrients should be leached out weekly to minimise salinity problems.

If nutrients are not provided in a slow release form, then Punstjarvi (1966) suggests that the larger the CEC the better the nutrient economy. Furata (1969) and Penningsfeld (1974) also recommend a CEC greater than 100 meq/L. An excessively high CEC in a growing medium would significantly increase salinity retention (Baker, 1957). High salinity may reduce the protective action of transpiration as water uptake is impeded. Root damage may occur through salt injury which could allow entry and development of root rot fungi (Bik, 1973). Salinity is unlikely to be excessive if conductivity of a saturation extract is 1.5-3.5 millimhos/cm (Baker, 1957).

(iii) Stability

A growing medium should be buffered to minimise pH fluctuations in the root zone which may contribute to the onset of micronutrient deficiencies and reduced growth.

Penningsfeld (1974) suggested the biological activity of the media should be low as microbial activity may result in uncontrolled decomposition or organic matter and mobilisation of nutrients. Davey (1955) noted that microbial action on organic amendments may double the estimated CEC in 16 weeks.

The medium should not release inorganic or organic compounds that may inhibit plant growth or development.

(3) Micronutrient problems in soilless growing media

The significance of trace element nutrition of plants is becoming more important with increasing use of soilless substrates coupled with slow release, high analysis fertilisers that are close to providing macronutrients at optimal levels and rates. Now, more than in the past some less apparent, but equally important nutritional factors may be growth limiting.

Laurie (1930) noted 'when peat is used alone as a medium for growing greenhouse crops, it proves to be an unsatisfactory substitute for the ordinary compost of soil and manure'. Laurie's report and many other such unpublished observations probably represent an interpretation of the use of peat substrates, made without sufficient knowledge of the many potential nutritional problems linked to trace element availability.

Deshusses and Duperrex (1952) observed that a range of plants could be grown very well in peat without visual trace element deficiency symptoms developing if supplied with a macronutrient liquid feed and 5-7% calcareous river sand incorporated into the medium. But amending the substrate with a clean silica sand produced unsatisfactory chlorotic plants.

In Europe peat is often used as the growing medium without amendment. Before the extensive use of micronutrients, optimal growth rates in containers were only achieved after adding 5-10% of a selected clay to the medium (Klougart and Olsen, 1969; Poole, 1969; Richards, 1974).

Some European pot plant growers may increase the proportion of clay in the medium to achieve better results. (Hoffmann and Fischer, 1973; Boertje and Bik, 1975).

The clay from different areas may vary widely in both chemical and physical properties, this may explain the adverse effect of clay addition to a growing medium as noted by Allerton (1958) and Sutton (1959) in England.

The inferior growth of celery and cauliflower in Einheitserde as noted by Heydemann et al (1952) may have been due to inadequate available B or Mo in the clay component of the medium.

Brown and Wilson (1971) observed that camellias became chlorotic and died soon after planting in pure peat, whilst plants in a sandy loam or combination of loam peat and sawdust remained vigorous and healthy after two years. This work could suggest the peat was very low in some essential factor required for plant growth and the addition of soil fulfilled this requirement.

Similarly Deen (1974) has noted that less foliar chlorosis occurred in conifers where sand and grit were added to peat compared with peat along.

Baker (1957) reported that in California, no trace element deficiencies or responses from added trace elements have been observed in the U.C. Mix. The sand component of the U.C. Mix usually comes from large areas of a suitable soil very high in fine sand. It is found in much of southern California. The base content of this poorly leached soil could be expected to satisfy the trace element requirements of plants grown in the U.C. Mix .

At 'the seminar of the century' Baker (1972) reported that deficiencies of Boron, Sulphur and Magnesium had been observed in isolated areas. These deficiencies have been attributed largely to the high purity of the water supply, but may also be due to inadequate supply of a particular element from the local sandy soil used in the growing medium.

Downes and Brickley (1957), in Ireland, investigated the potential of the U.C. Mix as a medium for tomato propagation. They found it necessary to add trace elements to the medium to achieve good results (Woods et al, 1968). The plant available trace elements in their media components were apparently less than those present in materials used by Baker.

Abnormal growth of chrysanthemums has been observed on a peat/sand substrate, particularly where the nitrogen source was hoof and horn. The application of more superphosphate or mixed trace elements reduced the problem (Bunt, 1961, 1962). The problem was later diagnosed as boron deficiency and readily corrected (Bunt, 1964, 1965).

Molybdenum deficiency has been reported in peat substrates used in horticulture (Roll-Hansen, 1966; Adams et al, 1972; Bunt, 1972; van den Ende and Boertje, 1972; Penningsfeld, 1973). Also, in 1966 copper and iron deficiencies were detected on plants growing in peat/sand substrates Bunt (1966) and later Adams et al (1972), Penningsfeld et al,(1973) and Smilde (1975). Copper deficiency has long been known to occur on reclaimed peat, Lundblad et al (1949). Low soil copper is still a problem in some areas of extensive horticulture today, on peat soil (Ng and Tan, 1974).

Interactions between Fe and Cu are known to occur on peat based substrates; the application of both Cu and Fe being required to fully correct iron chlorosis in some plants (Bunt, 1967; Cheshire et al, 1967).

Correction of micronutrient deficiences in the growing medium may be achieved by the application of inorganic salts containing the required elements. The inorganic salts, sodium borate, sodium molybdate and copper sulphate have proved useful in the correction of B, Mo and Cu deficiencies in peat based substrates (Puustjarvi, 1962; Bunt, 1964,1972; Penningsfeld and Heusler, 1965; Rolls-Hansen, 1966; Penningsfeld, 1972; Smilde and van Luit, 1972).

Bunt (1967), and Roll-Hansen (1966) have noted that inorganic iron salts did not supply iron in plants in an available form. Similarly in New Zealand, use of 'Sporomix PG' (commercial trace element mixture) did not prevent iron chlorosis development in soilless substrates. Where inorganic salts have failed to provide adequate Fe the use of chelated trace elements has proved more successful in fulfilling the Fe requirement in peat substrates (Roll-Hansen, 1966; Klougart and Olsen, 1967; Bunt, 1967; Deen, 1974).

Simple organic chelates (e.g. Fe-citrate, Fe acetate or Fe-EDTA) may allow rapid loss of their original clelated ion. Hence they may be of limited value when compared with more stable complexes e.g. Fe-EDDHA (Bunt, 1967; Pudelski, 1969; van Luit, 1972; Richards, 1974).

For a review of factors affecting chelate stability see Lehman (1963) and Norvel (1972).

Badger and Bray (1945) suggested using a slightly soluble glass carrier for minor nutrients required for plant growth. Since then, glassy frits have received considerable attention in agriculture

(Wynd and Stromme, 1951; Rhoads et al, 1956; Holden, et al, 1958; Henkins and Smilde, 1966; Sauchelli, 1969; Saxena and Locascio, 1975).

Most observed trace element deficiences in peat/sand substrates may be corrected by frit application (Bunt, 1964,65,71,72; Roll-Hansen, 1975). However Rhoads et al (1956) reports that FTE (Fritted Trace Element) materials supplied 'no more than a token amount of Fe to plants'. Similarly Smilde (1975) reported that straight (Fe) or mixed frits neither increased Fe content of plants or controlled leaf chlorosis. However, Bunt (1971) suggested that chelates and mixed or straight (Fe) frits were equally effective as iron sources, and in controlling leaf chlorosis. This work is contrary to the findings of Rhoads et al and Smilde.

Possibly the media used by Bunt has interacted with the micronutrients to generate the impression that frits and chelates were equally effective as Fe sources.

(4) Inertness of media components

The components of a growing media have long been held to be inert from a nutritional viewpoint. Baker (1957) has widely advocated the use of low fertility substrates to allow further quantification and control of the nutrient status in the medium.

Media components may be considered as basically two types:

(a) Organic material

Puustjarvi (1966) and Gallagher (1972) have said the nutrient content of peat is very low and is of no significance to plants. A comparison of the different nutritional requirements of plants when grown on peats of different origin, suggests that differences in micronutrient availability do exist (Chroboczek, 1963; Penningsfeld and Heusler, 1965; Van den Ende and Boertje, 1972; Smilde and van Luit, 1972).

Micronutrients (particularly cations) may bind with organic matter in a strong and often irreversible manner (Szalay and Szilagyi, 1969). Metal ions tend not to be adsorbed equally by all available sites. The first filled positions have a greater capacity for retention. These sites apoear to involve carboxyl and hydroxyl groups acting together (Davies et al, 1969). McLaren and Crawford (1974) report that only 20% of the adsorbed copper remained available after 24 hours.

Immobilisation of micronutrients may take place through the incorporation of the cation into highly favoured positions in organic complexes or by the formation of insoluble precipitates (Hodgson, 1963). Puustjarvi (1975) noted that humic acids associated with lignin content of peats were largely responsible for the fixing of nutrients in an unavailable form.

(b) Inorganic components

This fraction is generally considered to be less reactive than the organic fraction (Verdonck et al, 1974). Nevertheless, the release of bases (Cu, Mg + K) from exfoliated vermiculite (an inorganic media component) was known by Woodcock prior to 1946.

Significant surface activity of vermiculite has also been reported, retention of K, P and NH_4+ has been noted by Baikova and Vendilo (1972) and Bunt, (1974). Vermiculite also readily adsorbed Cu, Zn and Mn at low pH (Smith and Specht, 1952). A nutritional disorder of Red Oak, reported by Fenn and Durbin (1974) could be ameliorated by supplying extra calcium. They suspected Fe released by vermiculite may be limiting Ca availability. Somewhat dubiously, it was observed that Neumann and Prinz (1975) reported using vermiculite as an 'iron free media'.

Information related to perlite and pumice substrates is severely limited. Morrison (1956) and Matthews (1959), respectively considered perlite and pumice to be nutritionally inert. Perlite and pumice have relatively low cation exchange capacities(Morrison et al, 1960; Heck, 1971; Beel, 1974). Pumice has 'appreciable' capacity to adsorb macronutrients (McIlrath, 1950). Similarly, Esser (1973) reported that pumice had the capacity to remove nutrients from a nutrient solution but, perlite did not have this ability. The increased surface activity of pumice may be attributable to higher levels of hydrous manganese and iron oxides present within its siliceous matrix. These hydrous metal oxides are believed to be important regulators of micronutrient availability in soil and water (Jenne, 1968). However a large proportion (76%) of the Cu specifically adsorbed by iron and manganese oxides remains isotopically exchangeable (Mclaren and Crawford, 1974).

A veritable dearth of literature exists on the reactions of perlite and pumice with micronutrients.

In bonding of cations to soil surfaces Hodgson et al (1964) considered two possible types of reactions (i) hydrolysis of metal ion (m) followed by adsorption on an exchanger (X)

$$M^{+2} + H_2O \rightleftharpoons MOH^+ + H^+$$

$$MOH^+ + X^- \rightleftharpoons X\text{—}MOH$$

or in contrast (ii) surface exchange

$$M^{+2} + HX \rightleftharpoons X\text{—}M^+ + H^+$$

Perlite and pumice are considered to be largely composed of a three dimensional network of silicon and aluminium oxide tetrahedra (Keller and Pickett, 1954; Ralston, 1946). If polarisation of the surface and edge hydroxyls occurred, then some ion exchange reactions could be expected to take place (Fuller, 1971).

$$M - OH \xrightarrow{H^+} M^+ + OH^-$$

$$M - OH \xrightarrow{OH^-} M—O^- + H^+$$

The extent of cation adsorption and its reversibility is unknown for pumice and perlite.

Micronutrient cations may enter and leave the relatively open crystal structure of clay minerals by isomorphous substitution (Hodgson, 1963). This may explain Gogue and Sanderson's (1975) observations that foliage analysis of Chrysanthemum showed higher levels of K, Ca, Cu, Sn and Al when perlite was added to the growing medium. However, their use of multicomponent media makes interpretation of the results more difficult . Green (1968) noted increased aluminium content of Chrysanthemum and Carnation plants when grown in perlite at low pH. Green considered this was attributable to differential removal of Al from tetrahedral structure.

In conclusion, it may be seen that the reactivity of media components is poorly understood and are generally taken to be inert. Even recent publications have not given this factor the weighting it may deserve (Flegmann and George, 1975; Bunt, 1976). The unquestioning acceptance of such fixed ideas, serves only to impede further understanding and progress

(5) Rationale for experimental work

Suboptimal micronutrient availability may limit plant growth in soilless substrates, particularly where macronutrients are available at optimal rates.

A large volume of literature related to plant nutrition is available, however very little work has been carried out which is directly applicable to soilless substrates and allows the determination of an optimal nutrient supply.

Even today, where a plant growth response may be regarded as acceptable, it may be found that substantial improvements can be achieved by modification of the nutrient supply (Wilson, 1972).

Media components are generally considered to be inert, but observant growers and research workers have noted differences in plant growth associated with different growing media. This suggests that media components could be active in altering the availability of some essential plant nutrients. If the activity of media components were known, it should be possible to compensate for any restriction in nutrient availability or release of nutrients by altering a nutrient supply programme to produce closer to the optimum yield.

Analysis of selected plant material grown in standardised conditions is expected to reveal a certain nutrient composition. Where the availability of nutrients is sub-optimal this is expected to be reflected in changes in nutrient concentrations or nutrient ratios within the plant material (Bates, 1971). Nevertheless, the nature and extent of these changes may not be readily related to the nutrient supply or plant response. Despite this problem of interpretation, foliar analysis is widely used as a tool for the assessment of plant nutrient status (Walsh and Beaton, 1973).

The task of assessing the effect of some medium components on the nutrient content of plants grown in soilless substrates is seen as a study embracing a consideration of the following factors; chemical activity of media components, plant growth response coupled with foliar and media analysis from treatments bearing systematic variations. The soilless media used in these experiments were composed of one or two components, additional components would only serve to complicate the isolation of media specific effects.

This project is seen as identifying rather than elucidating some specific differences in micronutrient uptake from different soilless substrates.

CHAPTER 2

MATERIALS AND METHODS

(1) Plant Materials and Propagation Methods

(a) Chrysanthemum morifolium (Ramat) c.v. Nob Hill

This yellow flowered cultivar was selected as a test plant, as experience in the nursery industry has shown that it is more susceptible to nutritional disorders than many *Chrysanthemum* cultivars grown in New Zealand. Propagation was readily achieved from apical and sub-apical nodal cuttings. Basal leaves were removed from leafy cuttings 5-8 cm long (leaving 3 leaves) and the bases of the cuttings were dipped in 0.8% IBA in talc (Seradix III). The batch of cuttings was split in two and equal numbers were planted in cutting media made from either New Zealand peat and pumice or New Zealand peat and perlite. Cuttings were placed under intermittent mist until rooted (usually 10-14 days). During this period supplementary lighting was provided to prevent floral initiation. Rooted cuttings were potted into 10 cm PVC pots containing the particular media to be used in each experiment.

(b) Sorghum bicolor (Moench) c.v. RS 610

Sorghum was selected as a test plant because it produces easily-recognised visual symptoms of Fe deficiency (Sprague, 1964). If this plant could be grown in peat-pumice or peat-perlite then other plants less susceptible to Fe chlorosis may also be readily grown.

Propagation was effected by sowing seeds in trays of perlite or pumice. These were germinated in a lighted cabinet at 28°C. Sorghum plants (at 1 leaf stage) were pricked out into 12.5cm PVC pots containing the media used for Experiment 3b and 4b.

(c) Brassica chinensis (Linn.)

Chinese cabbages were grown as test plants to establish whether they would respond in the same way as Chrysanthemums when grown in artificial media.

These plants were raised from seed sown in trays of perlite or pumice in a lighted cabinet at 28°C. The seedlings were pricked out at the 3 leaf stage into 10 cm PVC pots filled with media for Experiment 3c.

(2) Media Components

The growing media were composed of two major components - an inorganic fraction (1) and an organic fraction (2).

(i) Inorganic fraction

(a) Perlite

Some acid volcanic rocks, notably glassy rhyolites intumesce on heating to form a cellular lightweight product (Ralston, 1946). When heated the combined water in each rhyolite particle expands to produce a white lightweight siliceous vesicular matrix. Currently ore from Atiamuri is expanded to produce a horticultural grade perlite.

(b) Pumice

Pumice, like perlite is also formed from acid volcanic rocks. The material is usually a light coloured vesicular glassy rock commonly having the composition of rhyolite (Gary et al, 1974) that is produced naturally as volcanic ejecta. The majority of the pumice used in New Zealand horticulture is river-washed material dredged from the Waikato river near Mercer.

(ii) Organic fraction

(a) Peat

Peat is the dark residium produced by partial decomposition of mosses, sedges, trees and other plants that grow in marshes and like wet places.

The horticultural quality peats used in the experiments were:

(i) The New Zealand peat was principally a mixture of sphagnum and sedge peats with a smaller proportion of restiad peat coming from near Torehape (Bates, 1973). This was baled and sold as Hauraki Peat.

(ii) The Irish peat available was a finely milled sphagnum peat. Before use both types of peat were passed through a 2.5 cm sieve to remove pieces of wood and other contaminants. The physical and chemical composition of these materials is summarised in Appendix I.

(3) Preparation of Growing Medium

The growing media were prepared by mixing equal volumes of an organic component with an inorganic component - Experiment 1, 2 and 3. In Experiment 4 only an inorganic component (either perlite or pumice) was used as the growing media.

Nutrients were added to the media, prior to mixing in an electric concrete mixer for a minimum time of 10 minutes. The standard nutrient supplement was intended to supply all the major nutrients for 10-12 weeks growth.

TABLE 1

Standard Nutrient Supplement per 10 litres of Growing Medium

Nutrient	Weight (g)
Osmocote 18:2.6:10 (N P K)	25
Osmocote 14:6:11.6	10
Superphosphate	15
Dolomite lime	15
Agricultural lime	15

To effect more even distribution of granulated superphosphate in the growing medium only the fraction that passed through a 2.5mm sieve was used. The fritted trace elements, FTE 503 and FTE 36, were added to the medium as required. These were added prior to mixing. The rate at which they were applied depended on the particular experiment.

One litre of water per 10 litres of medium was used to moisten the medium prior to mixing. After thorough mixing the media were stored in plastic bags for 2 days before use.

(4) Maintenance of Growing Conditions

Cutting material and material for some of the preliminary experiments were grown in the propagation house of the Horticulture Department, Massey University. The plants were grown in blocks, upon raised benches covered in a foam plastic pad (approximately 1cm thick). The glasshouse had a wooden frame. When required, ventilation was assisted by ridge vents and the doors were opened. The diurnal temperature variation was between 10°C and 25°C. Daily overhead watering was provided to all pots. Each day, water was applied until the foam mat was saturated. This provided a water reserve to minimise moisture stress during periods of high evapotranspiration.

Long day photoperiods were maintained in the glasshouse for an additional 5-6 hours after sunset. To achieve this, a number of 40 W lights were connected in parallel 1m apart and they were placed approximately 1m above the plants. The time period was controlled by a time clock.

The main experiments were conducted in one of Massey's Plant Growth Facility glasshouses. The glasshouse had a light aluminium and steel frame fixed to a solid concrete floor. The area of the glasshouse was approximately 36 square metres. Ventilation was achieved by the combination of hydraulically-operated louvre-vents and two variablespeed fans, all of which were controlled by a 'Pye Environment Control Module'. The day temperatures were maintained between 18-20°C and night temperatures were greater than 12°C, throughout the duration of the experiments. A thermostatically operated fan heater operated when the air temperature dropped below 15°C. Plants were grown on felt pads approximately 1m by 3m. The pads were watered daily for 2-3 hours by a spaghetti watering system, controlled by a solenoid valve and a time clock combination. Once a week plants were leached by overhead watering to remove excess soluble salts. Additional lighting, to prevent floral initiation was provided in the same manner as in the propagation house. Lannate (0.07%) sprays were applied as required to control aphids.

(5) Experimental design

The plant material used in each experiment was laid out in a randomised complete block design. Five replications of each treatment were used in each experiment.

A 10 week period was allowed for plant growth (unless stated otherwise), after which time leaf samples were taken for foliar analysis.

(6) Sampling

(a) Plant samples

(i) Chrysanthemum

Entire, expanded leaves in the upper quarter of the plant were removed for analysis as reported by Lunt et al (1964). Two plants per replicate were used to ensure adequate sample material.

(ii) Sorghum

Plants were cut at the base of the stem and the whole above ground portion of the plant used (Jones and Eck, 1973).

Each pot containing five plants was used for each replicate.

(iii) Chinese Cabbage

No specific sampling recommendations were available in the literature for chinese cabbage. However the suggestions of Jones and Eck (1973) were followed and the entire ground portion of the plant was used. Plants were grown one per pot, each representing a single replicate.

(b) Media samples

Cores, 2cm in diameter were taken from randomly selected pots within each treatment.

(7) Preparation of samples for analysis

(a) Plants

Freshly harvested plant material was washed in 0.1% Teepol, a mild detergent, for 10-15 seconds, then rinsed twice in distilled water. This was done as a precautionary measure to remove dust and media contaminants from foliage. Many researchers have shown that Fe could not be determined accurately if contaminants were present (Floyd and Rugland, 1966; Labanauskas, 1968). Excess water was removed before oven drying at 90-100°C for 24 hours.

The plant material was dried to a constant weight, cooled and the dry weight was measured before grinding. Plant samples were ground in a Glen Creston hammer mill, lined with a stainless steel liner to minimise contamination from the mill (Acquaye, 1967). Ground samples were then stored in sealed plastic containers.

Prior to weighing for ashing, each sample was mixed thoroughly with a stainless steel spatula to prevent separation of the fine and coarse particles. Variation in the nutrient concentration in different sample size fractions has been recorded (Jones 1963; Smith *et al*, 1968).

1.00g samples of the finely-ground plant tissue were weighed into silica crucibles and placed in an aluminium tray. The tray was covered to prevent contamination by particles from the refractory muffle furnace lining which had proved to be a problem in preliminary work.

The ashing procedure used was similar to that of Jones and Issac (1969) and Jones and Warner (1969). The aluminium tray containing the crucibles was placed in a muffle furnace at 500°C for 3 hours and then allowed to cool. The grey ash in each crucible was moistened with 5 drops of distilled water. One millilitre of conc. HNO_3 (Aristar) was carefully added to each crucible, which were then placed in an open oven at 120°C to dry. (Two to three hours later the ash was dry and quite black.) The crucibles were placed back on the tray, covered and placed in the muffle furnace for a further 15 minutes at 500°C to oxidise residual carbon. Labanauskas and Handy (1975) showed that loss of Cu, Fe, Mg and P could be related to residual carbon in the ash.

The crucibles were removed from the furnace and allowed to cool. Two millilitres of approximately 5N redistilled HCl were added to the brown ash residue in each crucible. Dissolution of the residue was assisted by stirring with a fine glass rod. The crucible contents were filtered through acid-washed Whatman 541 filter paper and transferred quantitatively to 10ml volumetric flasks and diluted to volume.

After mixing, samples were stored in glass vials until analysed. Reagent blanks for both plant and media analysis procedures were prepared and determined at the same time as samples.

(b) Media

Samples of media were air dried at 28°C for 3 days. 5.00g samples of media were shaken with 50ml of unbuffered 0.05 N Na_2EDTA on an orbital shaker for 24 hours.

[In preliminary work, the extractants 0.05 N $CaCl_2$ and 0.05 N Na_2EDTA were compared as suggested by Turner, 1975; Viro, 1955; Viets and Lindsay,

1973. EDTA appeared to extract a quantity of nutrients more closely related to plant uptake than the $CaCl_2$ and was more readily analysed, hence the use of $CaCl_2$ was discontinued.] The extract was filtered through acid-washed Whatman 541 filter paper and stored in glass vials until analysis.

The available phosphate in the media after five weeks use was estimated using Olsen's (1954) bicarbonate extractant in conjunction with the method of Murphy and Riley (1962).

(8) Preliminary investigation of some chemical properties of the media components.

(a) Cation Exchange Capacity

Using the method of Schollenberger and Simon (1945), 5.0g of a media component was leached with 100ml of neutral normal $NH_4C_2H_3O_2$. exchangeable Acidity was estimated by titrating the leachate back to pH7 with standardised 0.2N NH_4 OH(aq). The exchangeable bases were determined by evaporating the leachate followed by ignition overnight at 500°C. After cooling, 50ml of 0.2N HCl was added. Using a screened methyl-orange indicator, the excess acid was titrated with 0.2N NH_4OH(aq) and the exchangeable bases calculated from the differences in titre. See Appendix I (Table 47).

(b) Extractable nutrients

These were determined by shaking 5.0g samples of media components with 100mls of an extractant. Three extractants that differed in their capacity to alter the substrates were used, these were 1N $NH_4C_2H_3O_2$ (pH5), 0.05N Na_2EDTA and 0.05N HCl. After shaking three samples with the three different extractants (replicated five times) for 24 hours and filtering, the samples were analysed by atomic absorption spectroscopy (A.A.S) (see Appendix I) Table (48).

(c) Micronutrient sorption

5.0g samples of media components were shaken with 100ml of a 10ppm or 100ppm solution of one of the following salts: $ZnCl_2$, $CuCl_2$, $MnCl_2$, $FeCl_3$ (10ppm only) and Fe EDTA. The initial pH of all solutions was adjusted to pH5.0.

After staking for 24 hours samples were filtered and analysed by atomic absorption spectroscopy. The percentage adsorbed was then estimated, see Appendix I (Table 49). These results have not been discussed alone, but where appropriate within the text.

(9) Analytical Method

Elemental analysis of plant tissue and media extracts was performed by atomic absorption spectroscopy. Two instruments were used during the course of the experiments, a Techtron AA5 and a Perkin Elmer 306. The standard operating conditions used for each instrument and element were as suggested in their respective operating manuals. Samples were routinely analysed for Cu, Zn, Fe, Mn, Al, and occasionally for Ca, Mg, and K.

(a) Standard preparation

A 100ppm stock solution of Cu, Zn, Fe, and Mn was prepared in a 250ml volumetric flask from 1000ppm BDH atomic absorption standards, which were diluted with 2 N redistilled HCl. Concentrations used were 0, 1, 2, 5, 10, 15, and 20ppm.

A 100ppm Al standard was prepared by dissolving pure Al foil in 5 N HCl in a 100ml volumetric flask, and diluted to volume with 1 N HCl. Standards were prepared from the stock solution to cover the range 0-50ppm. Concentrations used were 0, 1, 2, 5, 10, 15, 20, 30, 40 and 50ppm.

Similarly, a 1000ppm combined standard of Ca and Mg was prepared from calcium carbonate and magnesium metal dissolved in 5 N HCl (Roth, 1969). Standard solutions of Ca and Mg should contain approximately 1% Lanthanum to prevent interferences from Al and Si. This may be achieved by diluting the stock solution with a suitable volume of 5% $LaCl_3$ and making up to volume with 1 N HCl. Standard solutions of 0, 1, 2, 5, 10, and 20ppm were prepared in this manner.

(b) Operating procedure for the estimation of Cu, Zn, Mn, Fe, Ca, and Mg.

A single slot air-acetylene burner was attached to the sample aspirator. After the fuel and air were turned on, the flame was adjusted to produce a small blue cone approximately 1cm high with the tip in the light path between the lamp and detector. Following a warm up period, the instrument was adjusted for maximum sensitivity at the particular wavelength selected for each element which corresponds with a strong absorption line. The concentration of each element was determined by comparing the absorbance of the sample with that of the standard.

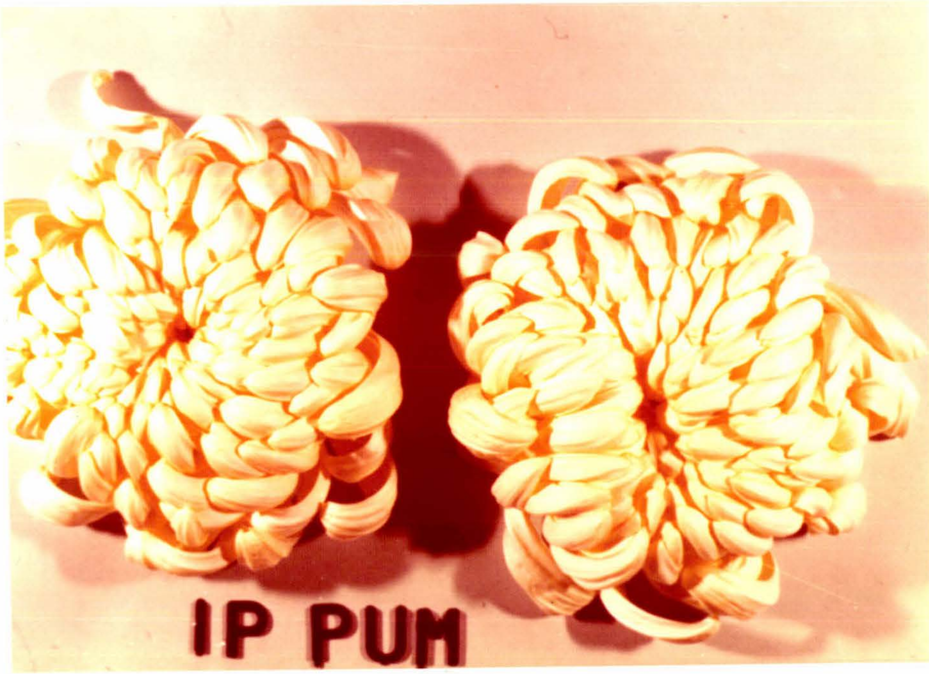
(c) Operating procedure for the estimation of Al

When samples were analysed by AAS for elements forming highly refractory oxides it was necessary to use a flame that was hotter than the air/acetylene combination in order to break the oxides formed in the flame into free atoms. This was achieved by using nitrous oxide as the oxidant and acetylene as the fuel. The mixture was burned in a special nitrous oxide burner. Particular care was required in the use of nitrous oxide and acetylene to prevent an explosive mixture being formed, which could result in the destruction of the aspirator (Brooks and Reeves, 1975). The nitrous oxide supply was adjusted to produce a flame with a red feather 1.5-2cm high above the white central cone of the flame, then the concentration of Al was determined by comparing the absorbance of the samples with the standards.

(10) Photographic Record

Typical leaves from plants samples were photographed using an SLR camera coupled with a 100mm macro lens. Artificial lighting was provided by electronic flash. Both Kodak Ektachrome and Agfa CT 18 films were used to make transparencies.

(i)



(ii)

Plate 1. First maturing Chrysanthemum 'Nob Hill' flowers grown in (i) Irish peat-pumice, (ii) Irish peat-perlite

CHAPTER 3

EXPERIMENTAL SECTION

The plant analysis data for each experiment are reported as micrograms of element per gram of oven-dried plant tissue. Chemical analyses of the growing media are expressed as micrograms of element per gram of air-dried media, appearing after the plant analysis data for the relevant experiments.

Data for Cu, Zn, Mn, Fe, and Al (where determined) are reported as the mean of five determinations and are tabulated in sections a, b, c, d, and e in each experiment.

Means followed by a common letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

Variance ratios for treatment effects and interactions were calculated to estimate significance, these data are summarised in Appendix II.

Preliminary work

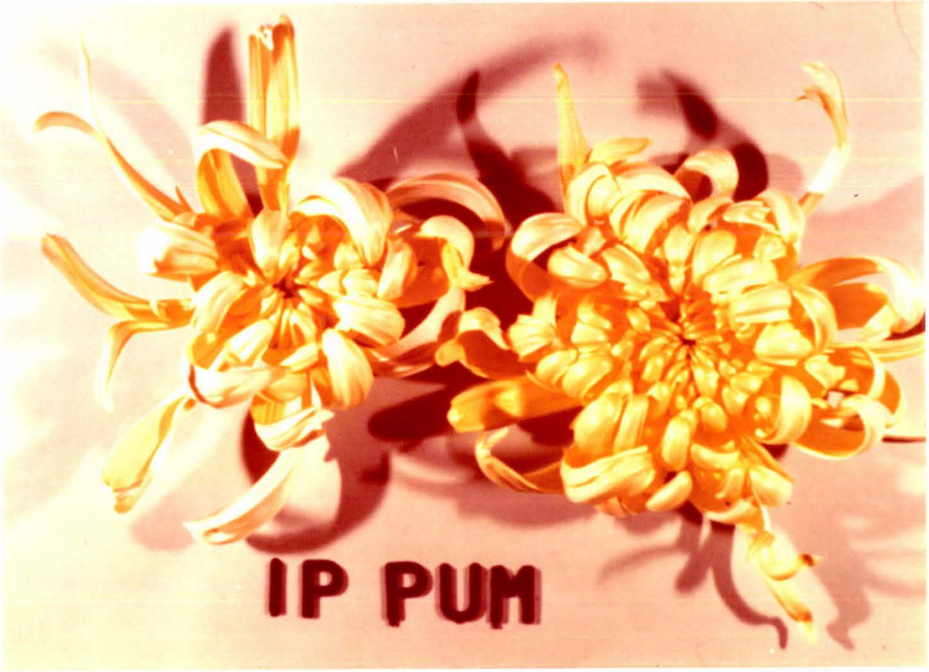
Chrysanthemum 'Nob Hill' plants were grown in 50/50 mixtures of peat and perlite or peat and pumice supplied with a normal macronutrient supply but no micronutrients were added, except those present as fertilizer contaminants.

Penningsfeld (1972) considered that plants may have to be grown in soilless media for several generations before nutrient deficiency symptoms would become apparent. This assertion was supported experimentally, as it was only after 3 generations of plants had been grown that differences in foliar colourationwere detected. Plants from the 4th generation were allowed to flower, the first flowers to mature, appeared healthy, but all flowers produced subsequently exhibited petal quilling typical of boron deficiency (Boodley and Sheldrake, 1973).

No difference was discerned between the Irish or New Zealand peats, hence only the media combinations using Irish peat are shown in Plates 1 and 2.

After removal of flowers, the new growth produced was used as the source of plant material for latter experiments in which Chrysanthemum was a test plant.

(i)



(ii)

Plate 2. Later maturing *Chrysanthemum* 'Nob Hill' flowers grown in (i) Irish peat-pumice, (ii) Irish peat-perlite showing boron deficiency symptoms

EXPERIMENT ONE

Chrysanthemum 'Nob Hill" plants were grown in four different media made from two inorganic and two organic substrates.

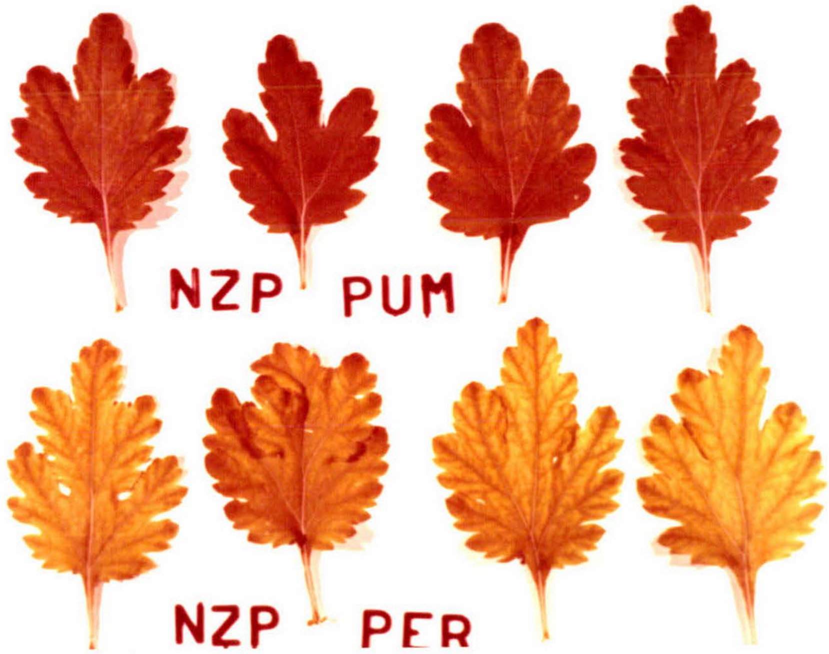
Nutrients were provided by the standard fertilizer supplement and FTE 503 was applied at two levels -0 and 75g/m^3.

Rooted cuttings were planted on 25 February and the plants allowed to attain a height of 55-60 cm prior to harvest on 6 June.

The foliage of all plants was a uniform bluish-green up until the 7th week. After this time plants in the perlite treatments were a lighter green than those in pumice treatments. The plants on the Irish peat/perlite treatments were beginning to show some interveinal chlorosis on the youngest leaves. This was most evident where FTE 503 was present. In the 8th week Chrysanthemum plants grown on New Zealand peat/perlite were also showing interveinal chlorosis, particularly where FTE 503 had been applied. One week prior to harvest, plants growing on Irish peat/pumice with added FTE 503 also showed chlorosis on the new growth, but not as distincly in the absence of FTE 503.

The colouration of leaves from plants grown in New Zealand peat/pumice with applied FTE 503 were darker green than any other plants grown with FTE 503. But even these leaves appear pale when compared with foliage from plants grown in New Zealand peat/pumice without FTE 503, see plates 3 and 4.

(1)



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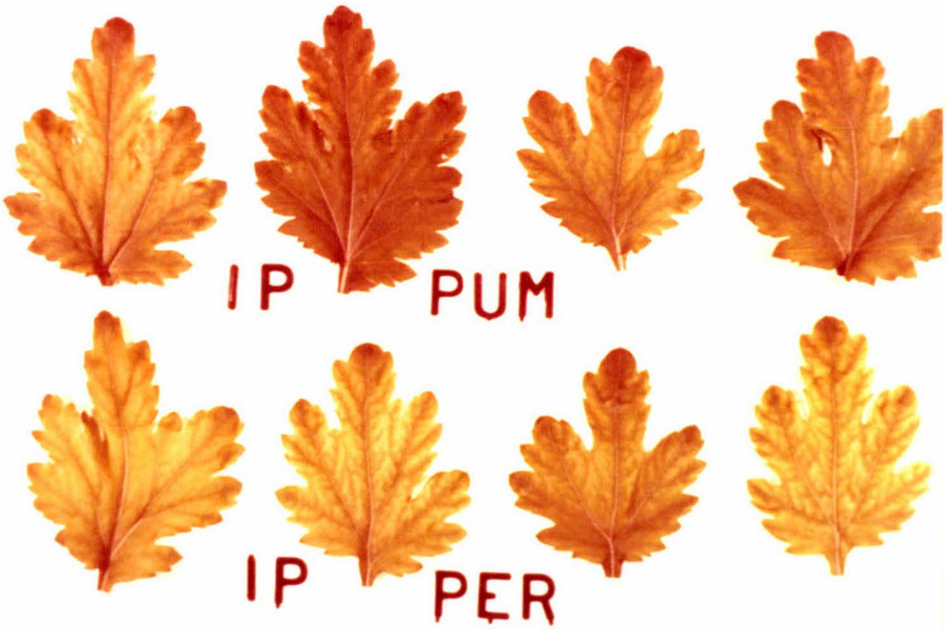


Plate 3 Foliage of Chrysanthemum 'Nob Hill' plants grown in
(i) New Zealand peat-pumice or New Zealand peat-perlite,
(ii) Irish peat-pumice or Irish peat-perlite, without added Frit

PLANT ANALYSIS RESULTS

(a) COPPER

TABLE NO 2

Micrograms of Copper per gram of Dried Chrysanthemum Foliage

Medium		FTE level (g/m^3)	
Organic	Inorganic	0	75
New Zealand peat	perlite	13.3.bc	14.5c
Irish peat	perlite	12b	11.9b
New Zealand peat	pumice	7.2a	7.8a
Irish peat	pumice	11.2b	12.5bc

LSD P=0.05 2.3
P=0.01 3.1

Where perlite was the inorganic component of the medium, there were differences between the effect of the two organic amendments on Cu uptake. Copper uptake was higher with New Zealand peat (NZP), although this was significant only when FTE 503 was added.

However, when pumice was the inorganic component, this trend was reversed, there being significantly more Cu uptake from Irish peat (IP) than that from New Zealand peat.

When mixtures with New Zealand peat as the organic fraction are compared, significantly more Cu uptake occurred from perlite than from pumice. With mixtures containing Irish peat this trend did not occur. This may suggest Cu is more available in IP than NZP and this could be masking any difference between inorganic components.

Addition of FTE 503 to mixtures produced only slight increases in Cu uptake which could suggest that the Cu was largely fixed in the medium,before it could be taken up by the plant.

(b) ZINC

TABLE NO 3

Micrograms of Zinc per gram of dried Chrysanthemum foliage

Medium		FTE level (g/m3)	
Organic	Inorganic	0	75
New Zealand peat	perlite	86.4cd	198.2f
Irish peat	perlite	92.8d	205.0f
New Zealand peat	pumice	71.2b	82.4c
Irish peat	pumice	58.6a	110.0e

LSD P=0.05 7.4
P=0.01 9.5

Where perlite was the inorganic component of the medium there was no significant difference in the level of Zn uptake from either peat source. There was however a trend towards higher uptake from the IP.

However, with pumice as the inorganic component, the pattern was less clear cut. Before the addition of FTE to the mixture the Zn level in plants was significantly lower where IP was used rather than NZP. But after the addition of FTE 503 this pattern was reversed. As this was an unexpected result an interaction between media components and the frit is suspected, alternatively some inherent variability in the media components may be responsible for this anomaly.

With either peat source, there was significantly greater uptake from Zn from perlite than from pumice.

The addition of FTE 503 to the mixtures significantly increased Zn uptake by Chrysanthemum plants.

(c) MANGANESE

TABLE NO 4

Micrograms of Manganese per gram of dried Chrysanthemum foliage

Medium		FTE level (g/m^3)	
Organic	Inorganic	0	75
New Zealand peat	perlite	107.2a	201.6d
Irish peat	perlite	101.2a	174.0c
New Zealant peat	pumice	148.0b	255.2e
Irish peat	pumice	164.8c	197.6d

LSD P=0.05 13.3
P=0.01 17.9

Where perlite was the inorganic medium component, more Mn uptake occurred with NZP rather than IP in the medium. This increase in Mn uptake was only significant after adding FTE.

Where pumice was the inorganic medium component, Mn uptake from NZP was significantly less than that from IP, prior to FTE addition; the situation was reversed after the addition of FTE.

With either peat source, the *Chrysanthemum* plants took up significantly greater quantities of Mn from pumice than from perlite. The addition of FTE 503 gave significant increases in Mn uptake from all media.

(d) IRON

TABLE NO 5

Micrograms of Iron per gram of dried Chrysanthemum foliage

Medium		FET level (g/m^3)	
Organic	Inorganic	0	75
New Zealand peat	perlite	61.6a	60.0a
Irish peat	perlite	104.4c	61.4a
New Zealand peat	pumice	93.2c	78.4b
Irish peat	pumice	127.2d	94.0c

LSD P=0.05 14.5
P=0.01 19.6

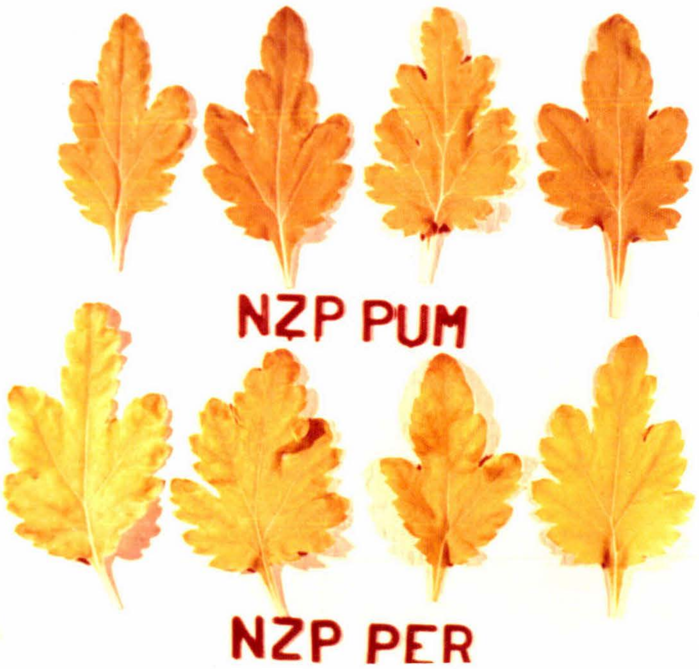
When perlite was the inorganic component of the medium significantly greater uptake of Fe occurred where IP was used, compared with that from NZP. Although, the same trend was present after FTE addition, the difference was not significant.

When pumice was the inorganic medium component significantly greater Fe uptake occurred from IP relative to that from NZP, irrespective of FTE level. These results could suggest the plant availability of Fe is relatively higher in IP than in NZP.

With either peat source, significantly more Fe uptake appeared to occur from pumice mixtures relative to perlite based mixtures, which may suggest that pumice supplies more plant available Fe than does perlite.

The addition of FTE 503 decreased Fe uptake in all treatments. A significant reduction in Fe uptake occurred in all media except NZP/per. These results suggest that an interaction between a frit component and Fe may be restricting plant uptake of Fe.

(i)



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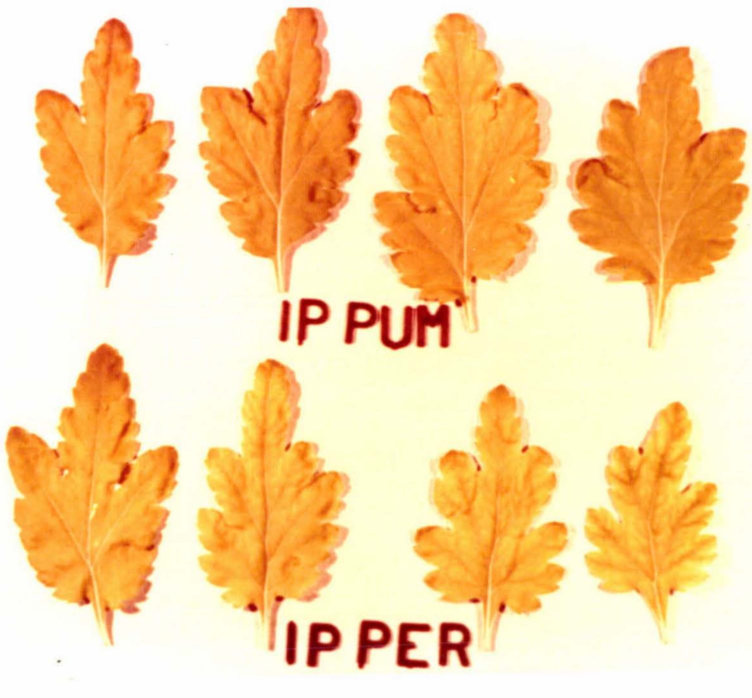


Plate 4 Foliage of *Chrysanthemum* 'Nob Hill' plants grown in
(i) New Zealand peat-pumice or New Zealand peat-perlite,
(ii) Irish peat-pumice or Irish peat-perlite, with added FTE 503

Discussion

Where perlite was the inorganic substrate, foliar Cu levels were higher where NZP was the organic media amendment than where IP was used. This result was unexpected, as preliminary work suggested that IP may have a higher level of extractable Cu than NZP, and that IP may have a lesser capacity to adsorb Cu than NZP. Where pumice was used in place of perlite, foliar Cu levels were higher where IP was the organic amendment rather than NZP. This is in accordance with expectations based upon preliminary observations.

Where IP was used in the medium there was no significant change in the level of foliar Cu where the perlite component was replaced by pumice. But with NZP in the medium, an interaction between the organic and inorganic media components was noted. Relative to IP, the addition of perlite to NZP increased foliar Cu, but the addition of pumice to NZP decreased foliar Cu levels. The significant OxI interaction observed, suggests that plant response is dependent upon the particular combination of media components. (See figure I overleaf).

The relatively small increase in foliar Cu levels after adding frit may be attributed to the relatively large Cu sorption capacity of the medium which may compete strongly with plant roots for Cu uptake. Henkens and Smilde (1966) also noted that some glassy frits did not effectively increase Cu uptake.

Where perlite was the inorganic substrate amendment, foliar Zn levels were higher where the organic amendment IP was used, rather than NZP. This result may have been anticipated, as Zn extractable from IP is higher than that from NZP. The relatively higher capacity of IP to adsorb Zn than NZP may explain why exchangeable Zn was higher from NZP than IP.

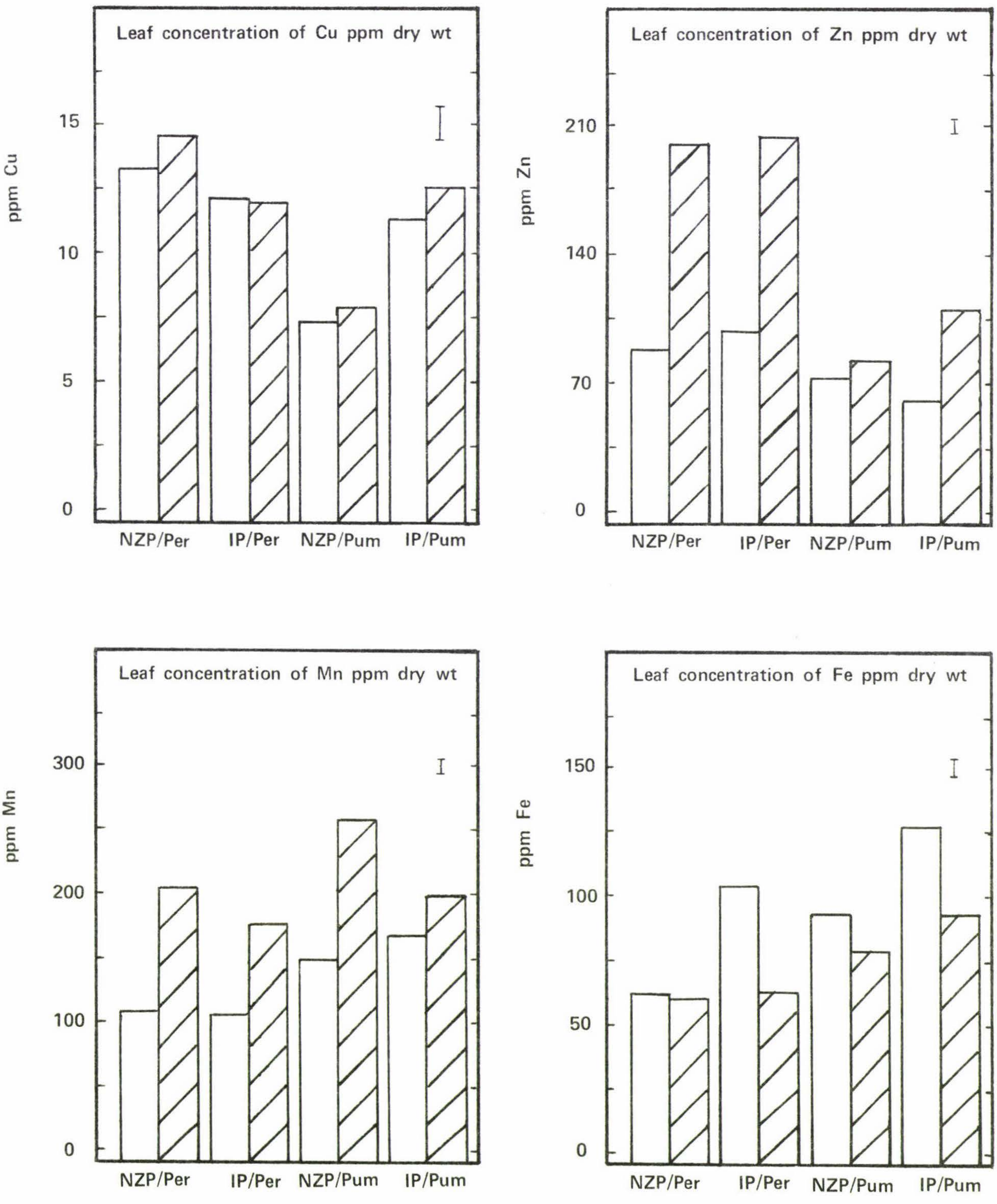


FIGURE 1

Influence of medium and level of Frit 503 on the concentration of micronutrients in *Chrysanthemum 'Nob Hill'.*

NZP = New Zealand Peat   Per = Perlite

IP = Irish Peat   Pum = Pumice

□ −FTE   ▨ +FTE   I LSD(0.05)

When pumice was the inorganic media amendment, foliar Zn was significantly higher where NZP was used instead of IP, but with frit added the trend was reversed and the plant response resembled that observed where perlite was used in the medium. This change in response may be attributed to undetermined variability in the media components that was masked by frit application.

Alternatively plant response to frit addition appears to be regulated by interactions between the frit and media components. This suggests foliar Zn levels are dependent on the particular combination of frit and inorganic or organic media components. The relatively larger increase in foliar Zn level following frit addition to perlite relative to pumice suggests perlite has less capacity to adsorb Zn from the frit, into a form unavailable to plants, than has pumice. This is confirmed by inspection of relative Zn sorption by each inorganic media component (see Table 49).

The frit and IP appear to have interacted with pumice, this interaction may have been responsible for the rather large increase in foliar Zn levels observed relative to the comparable NZP treatment (See figure I).

With no added frit, zinc levels in plants were significantly higher where perlite was the inorganic substrate instead of pumice. This suggests that perlite, itself, has a relatively larger capacity to supply plant available Zn than pumice.

In the absence of FTE 503 there was no difference in foliar Mn levels in plants grown in NZP/Per or IP/Per. The higher levels of extractable Mn, noted in IP relative to NZP did not appear directly related to plant availability (see table 48). But, where pumice was the inorganic media component foliar Mn was higher from plants grown in IP/Pum relative to NZP/Pum.

Plant response to the addition of frit to the medium appears to be controlled at least partly by interactions between the frit and medium components. Mn availability, after addition of frit, appears to be higher from media with NZP as organic media amendment rather than IP. This result corroborates well with preliminary work, which suggests NZP has less capacity to adsorb high levels of Mn than IP.

Manganese levels in plants were noted to be higher where the pumice was used rather than perlite, irrespective of the frit level. This suggests pumice may supply more plant available Mn than perlite, which may have been anticipated from the large difference in extractable Mn between these two media components (See table No 48).

Foliar Fe levels were notably higher where IP was the organic media component used, rather than NZP, irrespective of inorganic media components. Thus it would appear that more Fe is available to plants when IP is used in the medium rather than NZP. This contrasts markedly with the levels of extractable Fe, NZP appears to have more extractable Fe than IP. Perhaps the use of less disruptive extractants which assessed the size of the labile nutrient pool, and its relationship to less available nutrient pools, may have allowed a more reliable assessment of plant response (Graham, 1973).

Small differences in media pH do not appear to assist in prediction of plant response as proposed by Bradley and Smittle (1965). In this experiment the use of IP rather than NZP increased the media pH 0.2 units. An increase in media pH alone would not be expected to increase Fe availability (Wallace and Lunt, 1960).

Iron availability appeared to be higher where pumice was used in the medium instead of perlite. The availability of Fe appeared to be related to the higher levels of extractable Fe measured in pumice relative to perlite and less directly to the higher medium pH (0.4 units), measured on pumice amended media relative to perlite.

The addition of FTE 503 to each medium decreased Fe availability to Chrysanthemum plants (See figure I). A significant interaction F X I was detected, the plant response to added frit appeared to be dependent on the choice of the inorganic media component. From foliar Fe levels, it would appear that an interaction between Fe and element(s) derived from the frit, and/or the inorganic media component, reduced Fe uptake. Such interactions between macro or minor nutrients and Fe have often been reported (Olsen, 1972).

The levels of foliar Cu, Zn, Mn and Fe, measured in plants grown in each medium in this experiment would suggest that none of these particular elements were deficient (Criley and Carlson, 1970). However, after reference to colour plates 3 and 4 it may be seen that a disorder resembling a nutritional deficiency is present in some plants.

The plants grown with pumice in the medium appear to be less chlorotic than those with perlite in the medium. The effect of peat source was less than the inorganic media components on visual expression of chlorosis, although Irish peat appeared to increase the incidence of foliar chlorosis relative to NZP.

Addition of FTE 503 to the medium decreased the green colouration in all leaves from all media. Underlying this reduced pigmentation, the foliar symptoms present without FTE could also be observed.

This would suggest the inorganic media components are having an effect on foliar chlorosis that is not corrected by the addition of FTE 503, but is in fact aggrevated by this frit.

Owing to an international shortage of Irish peat, experiments with this material were discontinued.

EXPERIMENT TWO

Chrysanthemum 'Nob Hill' plants were grown in two media with two different nitrogen sources in each. The N sources were derived from slow-release fertilizers; sulphur coated urea (SCU) where nearly all the N was derived from ammonium ions, and Osmocote (OS), where N was derived from a balance of ammonium and nitrate ions. It was necessary to amend the standard fertilizer supplement to enable this to be achieved. Details of the amended supplements are shown in Appendix I (Table 51). Fritted trace elements (FTE 36) were applied at two levels - 0 and $200g/m^3$.

Rooted cuttings were planted in the growing medium on 26 August and the plants attained an average height of 60cm prior to harvest on 4 November. Plants were pinched soon after planting to promote the development of lateral buds. The plants with SCU as the N source showed some browning of their unexpanded leaf tips and marginal chlorosis on mature leaves after 10 days in the growing medium. The yellowing of the foliage was worse where perlite was used. At the same time a brown deposit was observed on the media surface of the perlite in the SCU treatment and a reddish-brown leachate was observed to come from these pots. Where OS was used as the N source, only very slight marginal chlorosis was observed on the mature leaves of the perlite treatments. Plants in pumice treatments did not show any chlorosis, irrespective of the N source.

After 3 weeks the interveinal and marginal chlorosis became more advanced on those plants in perlite mixtures with SCU, irrespective of FTE level. No chlorosis was observed on treatments with OS as the N source. Some chlorosis was observed on the raised parts of leaves from pumice treatments with SCU, irrespective of FTE level.

Strong leaching of all pots reduced marginal, but not interveinal chlorosis on the new growth. Some regreening of the chlorotic areas occurred. Addition of FTE 36 did not alleviate the interveinal chlorosis observed on the new growth in perlite mixtures. In pumice mixtures plants were uniformly green, irrespective of FTE level. After 8 weeks, the foliage of OS treatments appeared to be darker than foliage of SCU treatments, irrespective of media type (See plate 5).

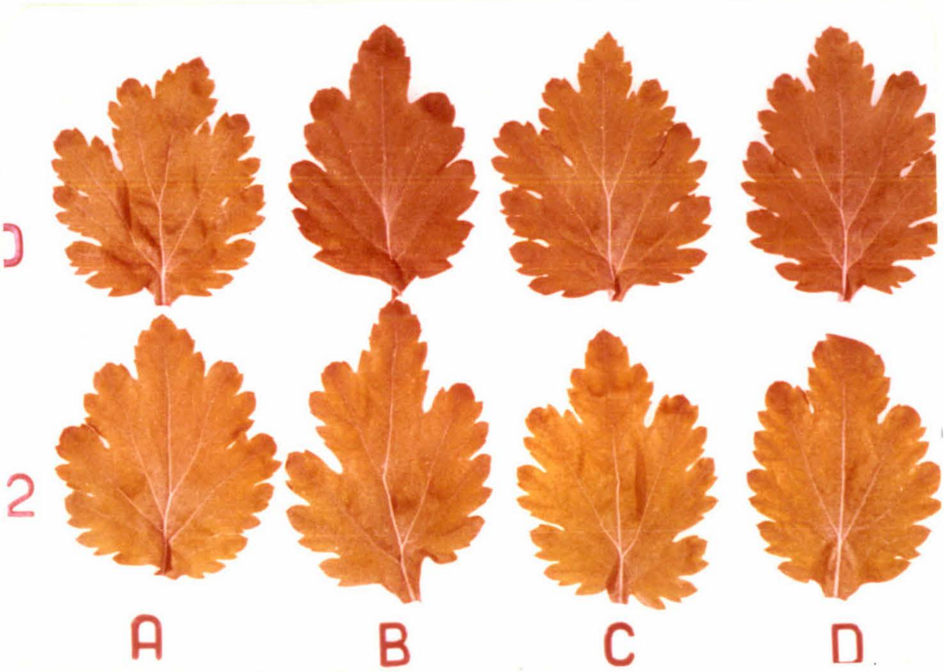


Plate 5 Foliage of *Chrysanthemum* 'Nob Hill' plants grown in New Zealand peat-pumice (A+B) and New Zealand peat-perlite (C+D) with an OS nitrogen source (B+D) or SCU nitrogen source (A+C), and with (2) or without (0) added Frit 36

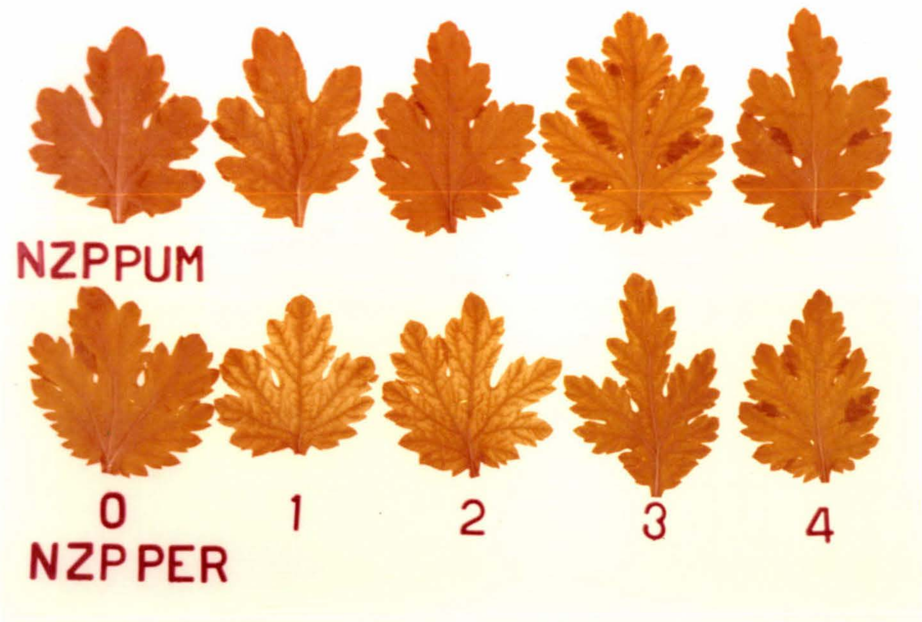


Plate 6 Foliage of *Chrysanthemum* 'Nob Hill' plants grown in New Zealand peat-pumice (top row) and New Zealand peat-perlite (bottom row) with Frit 36 added to the medium at 0, 100, 200, 300, and 400g/m^3 (left to right)

PLANT ANALYSIS RESULTS

(a) COPPER

TABLE NO 6

Micrograms of Copper per gram of dried Chrysanthemum foliage

Medium		N Source	FTE level (G/m3)	
Organic	Inorganic		0	100
New Zealand peat	perlite	SCU	14.2c	21d
New Zealand peat	perlite	OS	9.9b	13.6c
New Zealand peat	pumice	SCU	1.5a	3.0a
New Zealand peat	pumice	OS	2.9a	2.44a

LSD P=0.05 2.0
P=0.01 2.7

Where perlite was the inorganic component in the medium, a highly significant increase in plant-available Cu was observed when compared with plant uptake from pumice, irrespective of N source or FTE treatments.

When SCU was the N source, significantly more Cu appeared to be released from the medium for plant uptake,compared with OS in perlite mixtures. No significant N-source effect was observed when pumice was the inorganic fraction in the medium.

Where perlite was the inorganic fraction FTE 36 significantly increased foliar Cu levels, irrespective of the N source. However, where pumice was the inorganic fraction there was no significant increase in foliar Cu following the application of FTE 36.

(b) ZINC

TABLE NO 7

Micrograms of Zinc per gram of dried Chrysanthemum foliage

Medium		N Source	FTE level (g/m3)	
Organic	Inorganic		0	100
New Zealand peat	perlite	SCU	94.4e	102.4e
New Zealand peat	perlite	OS	43.2bc	70.0d
New Zealand peat	pumice	SCU	48.8c	40.4abc
New Zealand peat	pumice	OS	26.4a	29.6ab

LSD P=0.05 14.7
P=0.01 19.8

Where perlite was the inorganic component in the medium, a highly significant increase in foliar Zn was observed when compared with a pumice mixture, regardless of the N source or FTE treatments.

A highly significant increase in foliar Zn level was observed in a perlite mixture where the N source SCU was compared with OS. This effect occurred in both FTE treatments. Similarly with pumice mixtures, an increase in foliar Zn level was observed where the N source SCU was compared with OS. This increase was significant in the absence of FTE 36, but not after the addition of frit.

Addition of FTE 36 did not increase tissue Zn levels where pumice and SCU were present in a combined treatment, as it did in the other pumice mixture. In contrast, a significant increase in foliar Zn was recorded only where perlite and OS were present in a combinedtreatment, although the same trend was observed in the other perlite mixture.

(c) MANGANESE

TABLE NO 8

Micrograms of Manganese per gram of dried chrysanthemum foliage

Medium		N Source	FTE level (g/m^3)	
Organic	Inorganic		0	100
New Zealand peat	perlite	SCU	126.8a	244.8d
New Zealand peat	perlite	OS	209.6cd	174.4b
New Zealand peat	pumice	SCU	186.4bc	208.0bc
New Zealand peat	pumice	OS	211.6cd	219.2cd

LSD P=0.05 34.4
P=0.01 46.4

Where perlite and SCU were present as a combined treatment, significantly less Mn was absorbed by plants when compared with the comparable pumice mixture, in the absence of FTE 36. After adding FTE 36 the above perlite mixture appeared to release significantly more Mn for the plant uptake than the pumice mixture. Prior to adding FTE 36 to the mixtures with OS as the N source, no significant difference was observed between perlite and pumice, but after the addition of FTE 36, significantly more Mn appeared to be released from the pumice compared with perlite.

Where the N source OS was compared with SCU, then with OS slightly higher levels of Mn were observed in Chrysanthemum than with SCU, prior to adding FTE 36. After adding FTE 36, the same trend was present in pumice mixtures, but the reverse was true in perlite mixtures. However, overall no significant differences between N source treatments were observed.

Only a small increase in Mn level was observed after adding FTE 36 to mixtures with pumice as the inorganic medium component. This increase was not significant. Where perlite was the inorganic medium component, the addition of FTE 36 resulted in a significant increase in Mn level when SCU was the N source, but where OS was the N source there was a significant decrease in plant-available Mn.

(d) IRON

TABLE NO 9

Micrograms of Iron per gram of dried Chrysanthemum foliage

Medium		N Source	FTE level (g/m3)	
Organic	Inorganic		0	100
New Zealand peat	perlite	SCU	55.6ab	60.4ab
New Zealand peat	perlite	OS	59.0ab	51.4a
New Zealand peat	pumice	SCU	59.6ab	75.0c
New Zealand peat	pumice	OS	69.6bc	68.8bc

LSD P=0.05 14.7
P=0.01 19.8

A highly significant medium effect was observed. Where pumice was the inorganic component in the medium, higher levels of plant-available Fe were present, than in perlite mixtures. No significant differences were observed in the absence of FTE 36, but after adding FTE 36, pumice treatments appeared to release significantly more Fe than the equivalent perlite mixture.

Before adding FTE 36, the N source OS appeared to facilitate the release of Fe, but after the addition of FTE 36, it was SCU that appeared to increase Fe availability, irrespective of inorganic media components. Overall the effects of N source or FTE were not statistically significant.

MEDIA EXTRACT RESULTS

(a) COPPER

TABLE No 10

Micrograms of EDTA-extractable Copper per gram of growing medium

Medium		N Source	FTE level (g/m^3)	
Organic	Inorganic		0	200
New Zealand peat	perlite	SCU	5.6a	22.6c
New Zealand peat	perlite	OS	5.26a	23.2c
New Zealand peat	pumice	SCU	4.44a	13.66b
New Zealand peat	pumice	OS	6.54a	13.9b

LSD P=0.05 1.90
P=0.01 2.26

Prior to adding FTE 36, there was no significant differences in extractable Cu between perlite and pumice mixtures, irrespective of the N source. However, after adding the frit significantly more Cu was extractable from perlite mixtures than from pumice mixtures, irrespective of N source.

After adding FTE 36, Cu was more extractable from mixtures with Os than from mixtures with SCU, irrespective of the medium, but in the absence of the frit the two media responded differently. Where perlite was the inorganic component in the medium, Cu was more extractable when SCU was the N source. However, when pumice was the inorganic constituent in the medium, more Cu was extracted when OS was used. None of the differences relating to N source was significant.

A highly significant effect of adding FTE 36 was observed, irrespective of media or N source. The larger increase in extractable Cu occurred where perlite was the inorganic fraction in the medium.

(b) ZINC

TABLE NO 11

Microgr`ms of EDTA-extractable Zinc per gram of growing medium

Medium		N Source	FTE level (g/m3)	
Organic	Inorganic		0	200
New Zealand peat	perlite	SCU	60.9bc	107.8d
New Zealand peat	perlite	OS	68.4c	129.6e
New Zealand peat	pumice	SCU	34.0a	46.8ab
New Zealand peat	pumice	OS	45.6ab	56.0bc

LSD P=0.05 17.1
P=0.01 23.1

Where perlite was the inorganic component in the medium, a significant increase in extractable Zn was measured, when compared with pumice. This occurred irrespective of N source or FTE supply.

It was observed that where OS was the N source, Zn was more extractable from the medium than if SCU was the N source. However a significant N source effect was only realised where perlite and FTE were present in combination.

Increased extractable Zn was measured after the addition of FTE 36, irrespective of media or N source. Statistically significant increases were observed in perlite mixtures, but not in pumice mixtures.

(c) MANGANESE

TABLE NO 12

Micrograms of EDTA-extractable Manganese per gram of growing medium

Medium		N source	FTE level (g/m^3)	
Organic	Inorganic		0	200
New Zealand peat	perlite	SCU	9.4a	25.2b
New Zealand peat	perlite	OS	11.1a	30.4c
New Zealand peat	pumice	SCU	26.0b	34.8d
New Zealand peat	pumice	OS	23.8b	35.6d

LSD P=0.05 3.6
P=0.01 4.9

The increase in extractable Mn from pumice, relative to that from perlite mixtures was highly significant.

Where OS was the N source more Mn was extractable, irrespective of inorganic media components, compared with SCU as an N source. However, no significant N source effects were observed.

A highly significant increase in extractable Mn was observed where FTE 36 had been included in the media, irrespective of inorganic components or N source. The larger increase occurred where perlite was the inorganic media constituent.

(d) IRON

TABLE NO 13

Micrograms of EDTA-extractable iron per gram of growing medium

Medium		N Source	FTE level (g/m^3)	
Organic	Inorganic		0	200
New Zealand peat	perlite	SCU	241a	264b
New Zealand peat	perlite	OS	268bc	291c
New Zealand peat	pumice	SCU	414f	384e
New Zealand peat	pumice	OS	318d	371e

LSD P=0.05 23.2
P=0.01 31.3

A highly significant difference between the two inorganic media components was observed. Pumice appeared to supply significantly more extractable Fe than perlite, irrespective of N source or FTE levels.

In treatments where perlite was the inorganic component of the medium, OS appeared to cause larger significant increases in extractable Fe than did SCU. Where pumice was used in place of perlite this trend was reversed, and SCU caused greater increases in Fe release than did OS. Where FTE was added the differences were not significant in pumice mixtures.

In perlite mixtures the addition of FTE 36 increased the extractable Fe. The increases were significant where SCU was the N source and nearly significant (P = 0.05) where OS was the N source. Extractable Fe was increased where FTE 36 was added to a pumice medium with an OS N source.

However, where SCU was the N source, a significant decrease in extractable Fe was observed when FTE 36 was added to the pumice based medium.

Discussion

In perlite based mixtures higher levels of foliar Cu occurred when the N-source was SCU (initially ammonium N only) rather than osmocote (initially a balance of ammonium and nitrate N). Similarly Smith and Specht (1953) and Cheshire et al, (1967) noted Cu uptake increased where the N source was solely NH_4^+ relative to combination of NH_4^+ and NO_3^-, or NO_3^- alone. This information contrasts with Bunt's (1972) observation that foliar Cu was not affected by N-source.

The sulphur coating of SCU may have contributed in some undetermined manner to the increase Cu levels in foliage as noted by Adatia and Winsor, (1973).

However, with reference to Figure 2 it may be clearly seen that with pumice in the medium, no significant differences in foliar Cu levels were detected which could be attributed to N-source effects. A possible explanation for this may be related to the expected microbial activity in each medium. As the peat is heat treated, prior to packing, and perlite is strongly heated during manufacture, they would both be relatively sterile. Pumice sand, however is generally only river washed, and it is conceivable that this material may be innoculated with bacteria which accumulate in the Waikato river.

In the absence of competition,an initial innoculum of nitrifying bacteria may rapidly multiply in a medium and allow prompt conversion of ammonium nitrogen to nitrates, thus nullifying any N source effect or reducing possible ammonium toxicity. Repeating this experiment using pumice disinfected with methyl bromide [which is known to reduce nitrifying bacteria activity (May and Kempton, 1973)] may clarify this apparent difference between the two media.

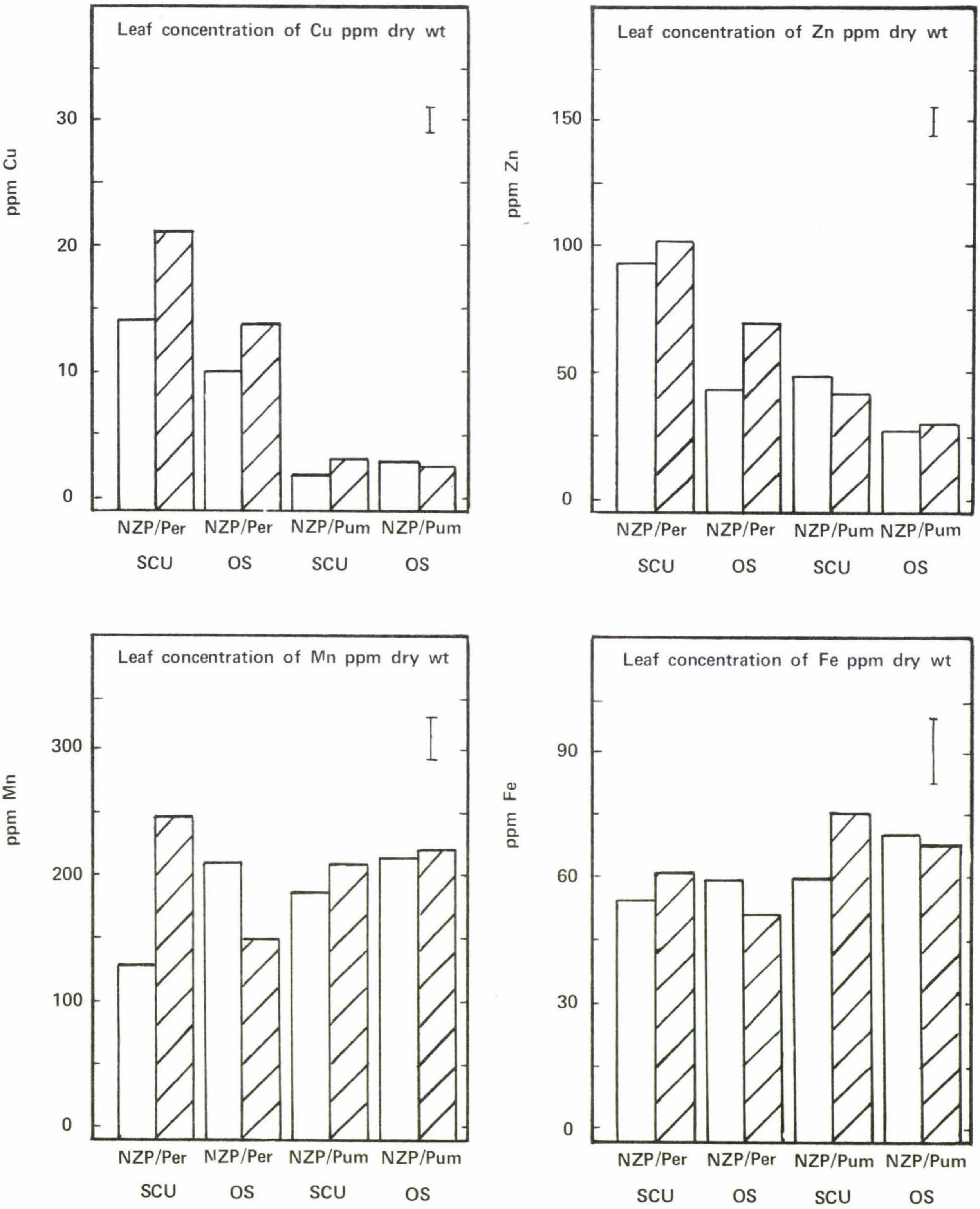


FIGURE 2

Influence of growing medium, nitrogen source and level of Frit 36 on the concentration of micronutrients in *Chrysanthemum 'Nob Hill'.*

NZP = New Zealand Peat

Per = Perlite

Pum = Pumice

SCU = Sulphur Coated Urea

OS = Osmocote

I LSD(0.05)

□ −FTE

▨ +FTE

Where perlite was used in the medium, significantly higher foliar Cu levels were noted, compared with those measured from a pumice based medium, which suggests perlite may supply relatively more Cu to plants than pumice. This is in accordance with results from preliminary work where each media component was extracted with $NH_4\ C_2H_3O_2$ and HCl, but not EDTA. EDTA extractions of each medium did not estimate levels of Cu that were directly related to foliar Cu. This is in contrast with Reith (1965) who considered EDTA was a good extractant for copper.

The nutrient pool explored by Chrysanthemum plants does not appear to be directly related to the nutrient pool available to the EDTA extractant, compare figure 2 and 3. The extent of overlap appears dependent on choice of media components. Plant response to frit addition appears to be regulated by frit interactions with media components and nitrogen source. The frit increased foliar Cu levels in NZP/Per but not NZP/Pum. EDTA extractable Cu increased with frit addition to either medium, the larger increase occurring on NZP/Per. These results coupled with information from preliminary experiments suggests that pumice has a larger capacity to fix Cu in a plant-unavailable form than perlite.

Both NZP/Per and NZP/Pum appeared to supply more plant-available Zn to Chrysanthemum where the N source was SCU instead of Osmocote, irrespective of frit level. Similarly, Viets et al (1957) noted increased Zn uptake in a medium with only an ammonium N source relative to a nitrate source. However, Bowan et al (1960) warns that this nitrogen source effect may be a plant-specific reaction.

Foliar Zn levels were higher, in Chrysanthemum plants growing in NZP/Per rather than NZP/Pum. This suggests perlite may supply relatively more Zn to plants than pumice (see Fig. 2). EDTA-extractable Zn also suggested a higher availability in NZP/Per than in NZP/Pum (see Fig. 3).

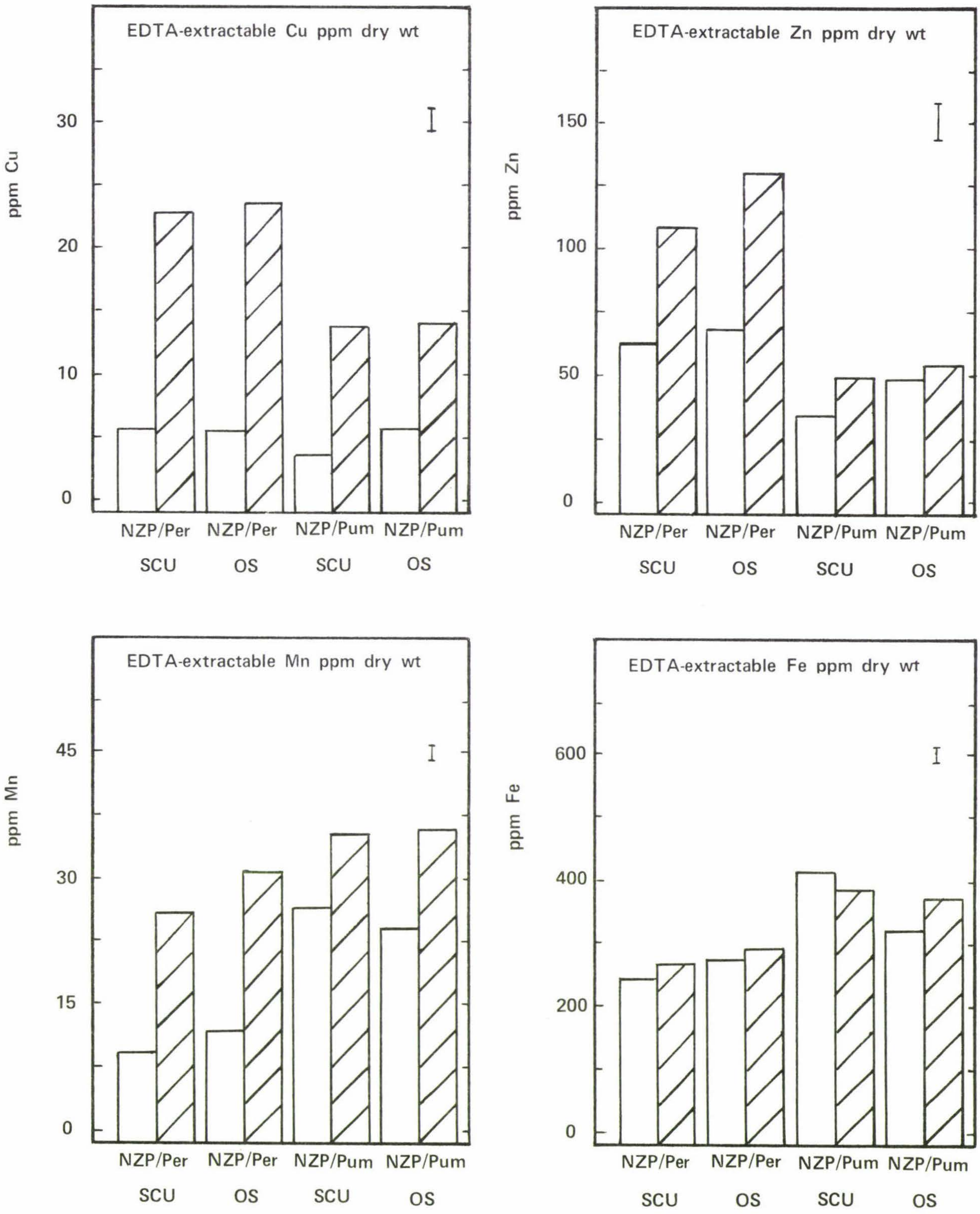


FIGURE 3

Influence of growing medium, nitrogen source and level of Frit 36 on EDTA-extractable micronutrients.

NZP = New Zealand Peat SCU = Sulphur Coated Urea

Per = Perlite OS = Osmocote □ −FTE ▨ +FTE

Pum = Pumice I LSD(0.05)

The addition of FTE 36, increased extractable Zn, (as with Cu), but this was not matched by a proportional increase in foliar Zn from NZP/Per. Addition of FTE 36 to NZP/Pum did not increase the EDTA extractable Zn or level of foliar Zn. This may suggest that with respect to Zn, the plant and the extractant experience similar difficulty in exploring the nutrient pool of NZP/Pum, but with NZP/Per as the medium, EDTA is able to tap a larger pool than is available to the plant. Thus it would appear that pumice based substrates exhibit a relatively larger capacity to restrict the extractability and plant availability of Zn than a perlite based medium. This is in accordance with the observation of Esser, (1973) and preliminary work.

Where NZP/Pum was the medium, foliar Mn was noted to be higher in treatments where OS rather than SCU was the N source. This corroborates well with observations of Smith and Specht (1953), and Bunt (1972) that an ammonium N source decreased Mn uptake relative to a nitrate source.

However, with NZP/Per as the growing medium this trend continued only in the absence of FTE 36. After adding frit to the medium foliar Mn was higher where SCU, rather than OS was used as the N source. An interaction between the frit and the sulphur from the SCU may have increased Mn availability, as observed by Adatia and Winsor (1973), and Stevens and Reuss (1975).

No significant effect of adding frit to NZP/Pum on foliar Mn levels was observed. Manganese from the frit appeared to be more EDTA-extractable than plant-available, compare figures 2 and 3.

The EDTA-extractable Mn differentiated between NZP/Pum and NZP/Per more successfully than Chrysanthemum plants. The relatively higher level of Mn in pumice than in perlite is not reflected in differences in foliar levels of similar proportions. However, the mean Mn level in foliage from NZP/Pum is higher than from NZP/Per which suggests the inorganic media components had a small effect on foliar Mn levels.

Foliar Fe in both NZP/Per and NZP/Pum was higher when used as the N source instead of SCU, prior to FTE 36 addition. After addition of frit the trend was reversed, higher foliar Fe occurring when the N source was SCU rather than OS. This reversal may be attributable to an effect of NH_4^+ or S either singly or together on the frit which promoted Fe uptake, as recorded by Cheshire <u>et al</u> (1967 and Adatia (1970).

The Fe extractable from NZP/Pum tended to be higher than that from NZP/Per, a similar trend was noted with foliar Fe levels. This is in agreement with results from preliminary experiments. The presence of SCU appeared to increase the level of Fe extractable from NZP/Pum, but no similar effect was noted with NZP/Per. This may have been due to the fact that EDTA has extracted almost all of the Fe added, (270 μg/g medium), to the medium by way of the Fe contamination present in lime, Dolomite, superphosphate and medium components (see table Nos 48 and 50). This figure corresponds closely with the Fe extracted from NZP/Per and could suggest that the N source would be unlikely to have a marked effect on Fe availability if there were no more extractable Fe present.

During (1972), considered that Olsen's bicarbonate extractable P was closely related to plant P uptake. When media extracts were analysed it became apparent that use of SCU increased extractable P relative to that of OS. This concurs with the work of Lorenz and Johnson (1953) who also observed increased P availability whilst using an NH_4^+ N source or following sulphur application. Extractable P was more available from NZP/Per than from NZP/Pum (see table 52).

At harvest time the foliage of plants grown in NZP/Per were more chlorotic than plants grown in NZP/Pum, and within each media treatment, the most chlorotic leaves were produced where the N source SCU was used.

From the data it appears that the highest levels of extractable P coincide with the worst foliar chlorosis (see plate 5).

The internal balance of P/Fe in Chrysanthemum may be related to foliar chlorosis as proposed by De Kock (1958).

The chlorosis noted soon after potting up also occurred on the treatments with SCU as the N source, however this chlorosis was considered to be attributable to ammonium toxicity due to a low nitrification rate in NZP/Per. The ammonium toxicity symptoms described by Massey and Winsor (1969) were similar to those observed here. Likewise the brown discolouration of young leaf tips could have been caused by excessive accumulation of amide nitrogen and phenolic compounds as recorded by Davies and Winsor (1971).

The nitrogen source appeared to influence the foliar level of the elements Cu, Zn and Mn more when NZP/Per was the growing medium instead of NZP/Pum. Nitrogen source had less effect on foliar Fe levels, compared with the other elements in either medium.

Plants grown in NZP/Per contained higher levels of Cu and Zn than those in NZP/Pum. Manganese and Fe levels tended to be higher where the substrate NZP/Pum was used instead of NZP/Per. This trend however, was not as distinct as that for Cu and Zn.

FTE 36 more effectively increased the levels of Cu and Zn in plants grown in NZP/Per than in NZP/Pum. The frit did not consistently increase foliar Mn or Fe in either medium. The addition of FTE 36 to each media appeared to increase the incidence of foliar chlorosis. This effect was most apparent where perlite was present in the medium (see plate 5).

Relative to the standard values tabulated by Criley and Carlson (1970) the levels of foliar Zn, Mn and Fe found in plants grown in all mixtures appear to be adequate for normal growth.

The fivefold higher level of foliar Cu derived from NZP/Per relative to NZP/Pum represents the largest observed nutritional difference between the two media. Whilst the plants growing in NZP/Per possessed adequate Cu, the level present in foliage from NZP/Pum would be less than the expected critical level (Nelson, 1971). The almost normal growth of *Chrysanthemum* 'Nob Hill' being devoid of copper deficiency symptoms, suggests this plant may have a lower Cu requirement than cultivars used by other workers (Nelson, 1971; Bunt, 1973; and Smilde, 1975).

If this were correct, then it may be possible that 'Nob Hill' is less tolerant of relatively high Cu levels than other *Chrysanthemum* cultivars (Woltz, 1956). The Cu levels in the plant and the medium may have been high enough to induce Fe chlorosis (Smith and Specht, 1953) as observed in some perlite mixtures.

As a visual Fe deficiency was not induced by the low level of available Cu in pumice mixtures this suggests that the Cu/Fe interaction noted by Bunt (1971) in *Chrysanthemum* may not operate in this cultivar.

EXPERIMENT THREE

Chrysanthemum 'Nob Hill' (Experiment 3A), *Sorghum* 'RS 610' (Experiment 3B) and Chinese cabbage (Experiment 3C) plants were grown in New Zealand peat/perlite or New Zealand peat/pumice. Fritted trace elements (FTE 36) were applied at 5 levels - 0, 100, 200, 300 and 400 g/m^3.

EXPERIMENT 3A

Chrysanthemum 'Nob Hill' plants were grown in two different media and fritted trace elements were applied at 5 levels. Rooted cuttings were planted on 11 June and the foliage harvested for analysis 10 weeks later on 20 August. During the growing period all plants attained a height of 70-80cm.

Interveinal chlorosis on the foliage of Chrysanthemum plants grown in perlite mixtures occurred often, but its incidence did not appear to be related to FTE level. All plants in these mixtures exhibited some interveinal chlorosis in the raised parts of the leaf lamina. These leaves did not regreen with advancing age (see Plate 6). Randomly located throughout each block were plants in perlite treatments which produced more severe foliar chlorosis symptoms.

Treatments with pumice as the inorganic substrate produced plants with darker green foliage than all the perlite treatments (See Plate 6). Some plants growing adjacent to perlite treatments exhibiting very marked chlorosis, would also show interveinal chlorosis, but to a lesser extent on the youngest mature leaves.

PLANT ANALYSIS

(a) COPPER

TABLE NO 14

Micrograms of Copper per gram of dried Chrysanthemum foliage

Medium		FTE level (x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	Perlite	4.7a	15.9cd	18.4d	21.7e	24.4f
New Zealand peat	pumice	4.0a	12.0b	15.8cd	17.5cd	15.4c

LSD P=0.05 2.6
P=0.01 3.4

With perlite as the inorganic substrate more uptake of Cu occurred than with pumice mixtures irrespective of FTE level. Significant differences between these two substrates occurred where the fritted trace element supply was 100, 300, and 400 g/m^3. (Significance at the 200 g/m^3 level was almost obtained at P = 0.05).

Frit addition to perlite mixtures significantly increased plant uptake of Cu, for all treatments above the nil FTE treatment. Treatments 1 & 2 were not significantly different from each other. All other treatments were significantly different from each other. Similarly in pumice mixtures, added FTE 36 increased Cu uptake above the nil FTE treatment. Treatments 2,3 & 4 were not significantly different from each other, as were treatments 0, 1 & 2.

With pumice in the medium, maximum uptake of Cu occurred where 300 g/m^3 FTE 36 was applied to the medium. Where perlite was used, the tissue Cu level reached a maximum at the highest applied frit rate.

(b) ZINC

TABLE NO 15

Micrograms of Zinc per gram of dried Chrysanthemum foliage

Medium		FTE level (x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	54.8c	102.4d	125.2e	153.2f	166.4g
New Zealand peat	pumice	26.6a	27.9a	33.2ab	37b	42.4b

LSD P =0.05 9.0
P==0.01 12.0

Where perlite was the inorganic fraction of the medium, significantly more plant uptake of Zn occurred, than that from pumice mixtures.

Addition of FTE 36 to perlite based media significantly increased the Zn uptake above the nil FTE treatment. All treatments were significantly different from each other.

Where pumice was the inorganic fraction, increased application of FTE 36 increased plant uptake of Zn. However, treatments 0, 1 & 2 were not significantly different. Similarly treatments 2, 3 & 4 were not significantly different from each other. Foliar Zn levels from treatments 0 & 1 were significantly different from 3 & 4.

The highest level of Mn uptake from both media occurred where the highest rate of FTE 36 was used.

(c) MANGANESE

TABLE NO 16

Micrograms of Manganese per gram of dried Chrysanthemum foliage

Medium		FTE level (x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	54 a	64.2a	56a	68.4a	85.2a
New Zealand peat	pumice	175.2b	142b	158b	230c	284d

LSD P=0.05 33.6
P=0.01 45.1

Significantly more plant uptake of Mn occurred from pumice based mixtures than from perlite based mixtures, irrespective of frit level.

When FTE 36 was added to New Zealand peat/perlite a small but non-significant increase in Mn uptake was observed. With New Zealand peat/pumice, application of FTE 36 increased plant uptake of Mn. Manganese uptake from treatments 0, 1 & 2 were not significantly different. Uptake of Mn from treatments 2, 3 & 4 was significantly different. Maximum uptake of Mn from both media occurred with the highest frit level used.

(d) IRON

TABLE NO 17

Micrograms of Iron per gram of dried Chrysanthemum foliage

Medium		FTE level (x100 g/m3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	87.2	110	100.4	148	122.8
New Zealand peat	pumice	140.0	136	119.2	98.8	122.0

No significant treatment effects were observed. Neither the inorganic substrates or FTE level appeared to show any consistent effect on foliar Fe levels. Overall, where perlite was the inorganic media amendment, added FTE 36 increased Fe uptake above the nil FTE treatment. In contrast, in pumice based mixtures the addition of FTE 36 appeared to decrease Fe uptake below that of the nil FTE treatment.

(e) ALUMINIUM

TABLE NO 18

Micrograms of Aluminium per gram of dried Chrysanthemum foliage

Medium		FTE level (x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	11a	22abc	11a	13ab	16ab
New Zealand peat	pumice	38de	30cd	24bc	46e	29cd

LSD P=0.95 10.9
P=0.01 14.6

A significant increase in plant uptake of Al occurred from pumice based mixtures compared with the corresponding perlite mixtures, with one exception. Where 100 g/m^3 of FTE 36 was applied, no significant difference between pumice and perlite was observed, although the same trend was continued.

A significant frit effect was observed, but no pattern was discerned. No significant increases in Al uptake occurred with increased FTE levels in perlite mixtures, the highest level of foliar Al occurred in treatment 1. Similarly, in pumice mixtures the significant increases in Al uptake did not appear to be directly related to FTE level, the highest level of foliar Al occurred in treatment 3.

EXPERIMENT 3B

Sorghum 'RS 610' plants were grown in two different media. Fritted trace elements (FTE 36) were applied at 5 levels.

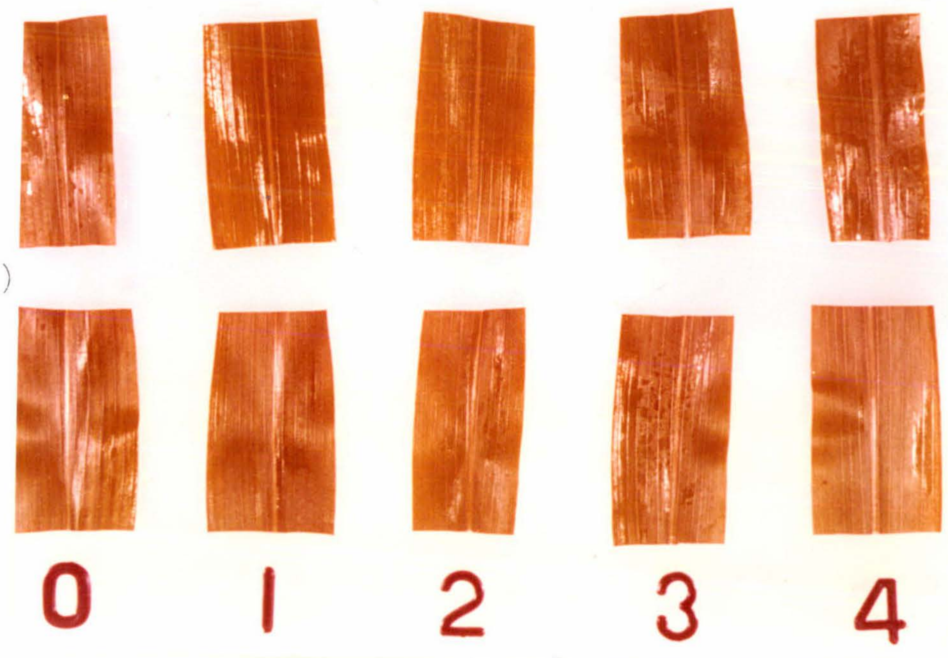
Sorghum seed was sown in pots on 14 August and thinned to 10 plants per pot on 21 August. Harvest date was 23 October.

No observable differences in foliage colour occurred until about the fourth week. After this time, some interveinal chlorosis became apparent on young expanding leaves from plants grown in perlite mixtures, this occurred irrespective of FTE level. In pumice mixtures, where interveinal chlorosis was observed, it was on individual plants and did not appear related to any specific treatment effect.

No visual effects attributeable to FTE level were observed. Within each media type, foliar colouration was similar for all FTE levels (see plate 7).

Plants grown in perlite based media tended to be larger than those grown in pumice based media. This was borne out by their wet weights, but not their dry weight estimates. The leaves and stems from plants growing in perlite mixtures were harder and more abrasive than those produced by plants growing in pumice mixtures. Similarly, 2-3 times more acid-insoluble residue remained after ashing plant samples from perlite mixtures, compared with those from pumice mixtures.

(i)



(ii)

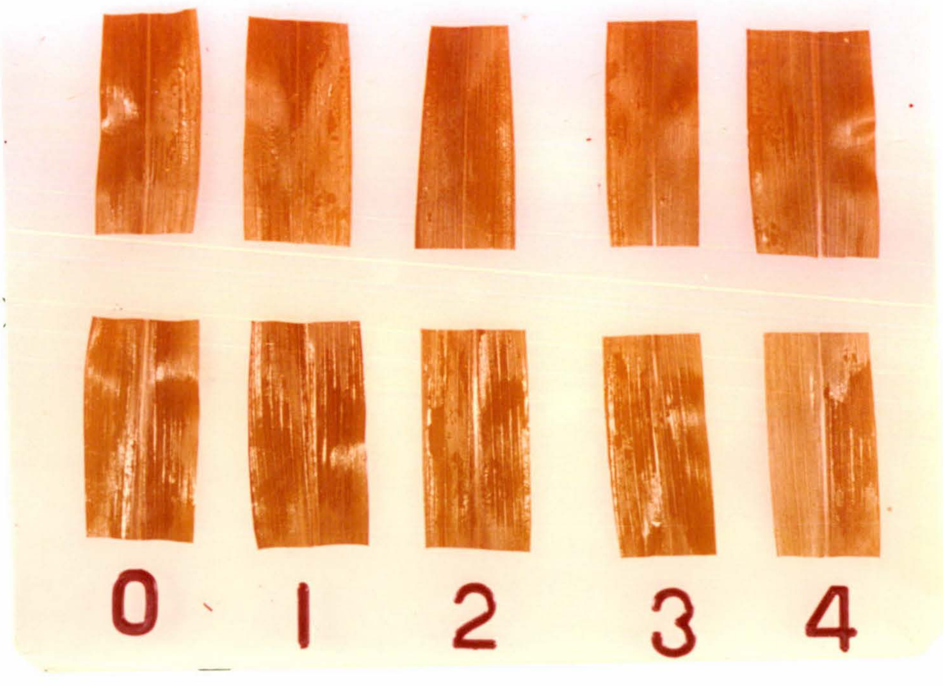


Plate 7 Foliage sections of Sorghum 'RS610' plants grown in (i) New Zealand peat-pumice and (ii) New Zealand peat-perlite with Frit 36 added to the growing medium at 0, 100, 200, 300, and 400g/m^3 (left to right)

PLANT ANALYSIS

COPPER

TABLE NO 19

Micrograms of Copper per gram of dried Sorghum foliage

Medium		FTE level (x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	4.3a	14cd	11.8c	14cd	14.9d
New Zealand peat	pumice	5.4ab	7b	12.5cd	12c	13.4cd

LSD P=0.05 2.3
P=0.01 3.1

Mixtures with perlite as the inorganic fraction appeared to release a little more Cu for plant uptake than comparable pumice mixtures. A significant increase in Cu uptake occurred only in the treatment with 100 g/m^3 FTE 36 added.

A significant effect of adding FTE 36 to both media was noted. Where perlite was the inorganic substrate, the Cu uptake from each group of treatments 1 & 2, or 2, 3 & 4 were not significantly different from each other, but treatments 0 & 1 were significantly different from each other. In pumice based mixtures Cu uptake from treatments 0 & 1 were not significantly different. Similarly, significant differences in Cu uptake were not observed between treatments 2,3 & 4 but were noted between treatments 1 & 2.

Maximum plant uptake of Cu from both media occurred with the highest frit level used.

ZINC

TABLE NO 20

Micrograms of Zinc per gram of dried Sorghum foliage

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	75b	90.2c	98.4c	130d	148e
New Zealand peat	pumice	51.8a	59.6b	67.4ab	71.8b	116.8d

LSD P=0.05 17.0
P=0.01 23.0

A significant increase in Zn uptake by Sorghum was observed where plants were grown in media with an inorganic fraction of perlite rather than pumice, irrespective of FTE level.

Application of FTE 36 significantly increased Zn uptake from all perlite mixtures above the nil FTE level. Treatments 1 & 2 were not significantly different, as were all other treatments. Applied FTE 36 increased Zn uptake from all pumice based mixtures, but treatments 0 & 2, or 1, 2 & 3 were not significantly different from each other.

The maximum plant uptake from both media coincided with highest FTE level used in each medium.

MANGANESE

TABLE NO 21

Micrograms of Manganese per gram of dried Sorghum foliage

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	98a	154bc	184d	158bcd	173cd
New Zealand peat	pumice	138b	164bcd	148bc	159bcd	158bcd

LSD P=0.05 25.8
P=0.01 34.7

No significant differences in Mn uptake between the two media were observed.

A significant increase in Mn uptake occurred after adding FTE 36 to the perlite based mixtures relative to the nil FTE treatment. Manganese uptake from treatments 1, 3 & 4, or 2, 3 & 4 were not significantly different from each other. When pumice was the inorganic substrate, no significant increase in Mn uptake was associated with increased FTE level. Maximum Mn uptake from perlite and pumice mixtures occurred where 200 and 100 g/m^3 of FTE 36, respectively had been applied.

IRON

TABLE NO 22

Micrograms of Iron per gram of dried Sorghum foliage

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	57.4	46.4	77.8	71.8	81
New Zealand peat	pumice	70.6	76.2	69	78.2	70.8

No significant differences between media, or frit levels were observed. Fe uptake from treatments 0 & 1 in the NZP/Per medium were low compared with all the other treatments which were comparable.

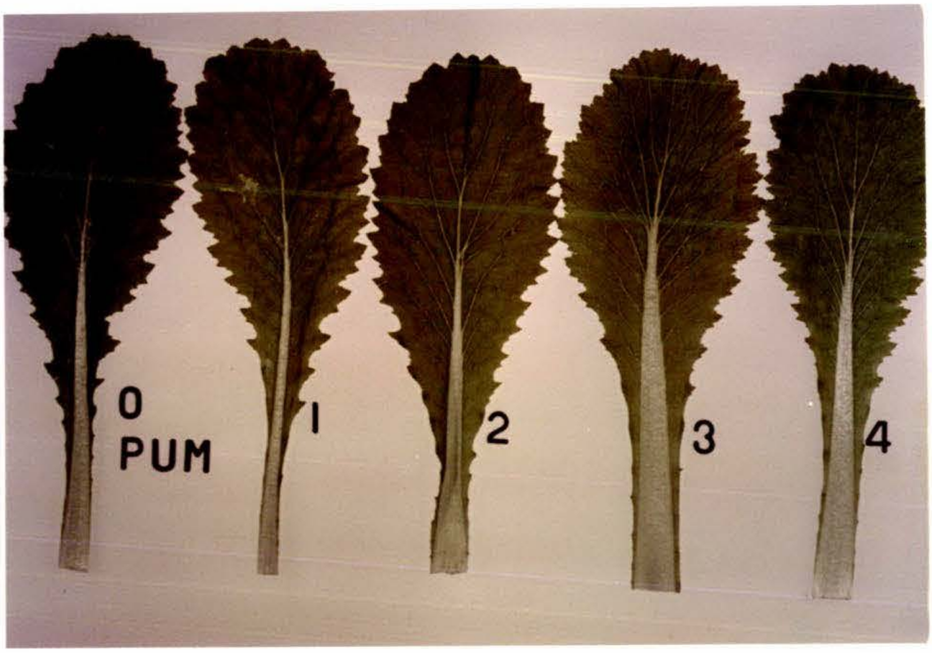
EXPERIMENT 3C

Chinese cabbage plants were grown in two different media and fritted trace elements (FTE 36) were applied at 5 levels. The planting date was 16 June and after 10 weeks, on 25 August the tops, excluding cotyledons were harvested for chemical analysis.

No differences in foliage colouration due to treatment effects were observed up until the fourth week. At this stage, the new foliage of plants in perlite mixtures was becoming a lighter green than that from pumice mixtures. After the sixth week the raised interveinal areas of foliage from perlite based media was much lighter than the corresponding areas on Chinese cabbage from pumice mixtures (refer to plate 8). At this stage leaves from pumice treatments were a much darker green, but were lighter around the periphery of each leaf. Foliar symptoms were similar after a period of 10 weeks, as seen in plate 8.

Usually, most growth occurred in the perlite treatments with 200 and 300 g/m^3 FTE 36 applied, and in pumice treatments with 100 and 200 g/m^3 FTE 36. Least growth occurred in the nil FTE treatment with NZP/Per as the growing medium. This was confirmed by wet weight and dry weight determinations.

(i)



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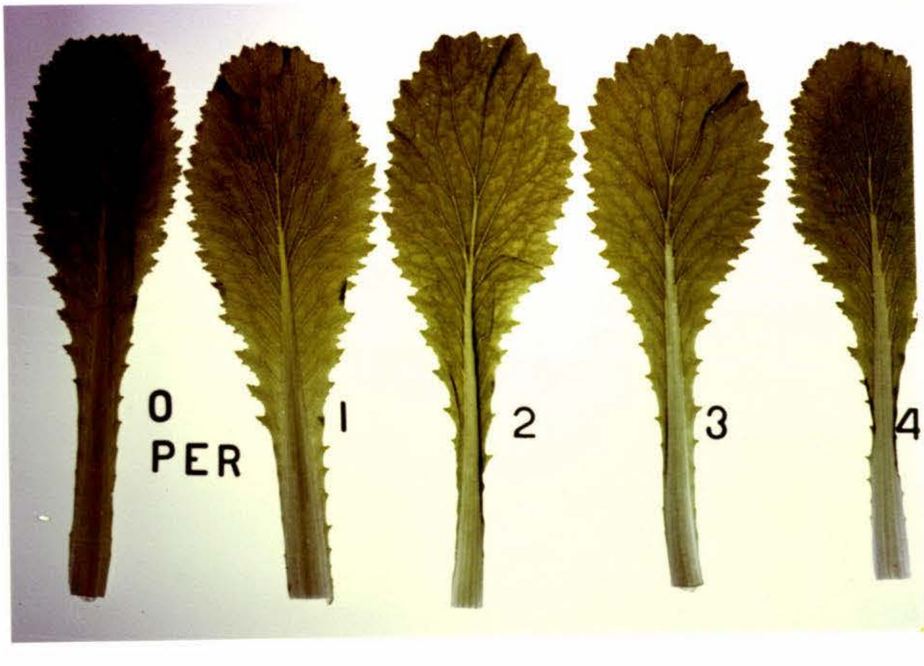


Plate 8 Foliage of Chinese Cabbage plants grown in (i) New Zealand peat-pumice and (ii) in New Zealand peat-perlite with Frit 36 added to the growing medium at 0, 100, 200, 300, and 400 g/m^3 (left to right)

PLANT ANALYSIS

COPPER

TABLE NO 23

Micrograms of Copper per gram of dried Chinese Cabbage foliage

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	7.4a	11.3b	15.2d	21.4e	22.4e
New Zealand peat	pumice	6a	7.2a	11.6b	13bc	14cd

LSD P=0.05 1.9
P=0.01 2.5

In perlite mixtures,significantly higher levels of foliar Cu occurred than were detected in pumice mixtures where FTE 36 was present. The same trend was observed with nil FTE treatment, although the difference was not significant.

A highly significant effect of adding FTE 36 to both media was observed. Maximum uptake of Cu from both media occurred with the highest level of FTE 36. In trials with perlite as the inorganic fraction, Cu uptake from all treatments except 3 & 4 were significantly different from each other. Where pumice was the inorganic fraction Cu uptake from treatments 0 & 1 were not significantly different. Similarly, treatments 2 & 3, or 3 & 4 were not significantly different.

ZINC

TABLE NO 24

Micrograms of Zinc per gram of dried Chinese Cabbage foliage

Medium		FTE level(x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	95.2bc	104c	129.2d	185.2e	184.4e
New Zealand peat	pumice	70.4a	78.8ab	106.4c	131.6d	139.2d

LSD P=0.05 20.5
P=0.01 27.5

Zinc uptake from perlite mixtures was significantly higher than that from pumice mixtures irrespective of FTE level.

Addition of FTE 36 increased plant uptake of Zn from both media. For both media it was found that Zn uptake from treatments 0 & 1, or 3 & 4 were not significantly different from each other. Treatments 1, 2 & 3 were significantly different from each other. The highest levels of foliar Zn occurred where the added FTE rate was 300 and 400 g/m^3 in perlite and pumice mixtures respectively.

MANGANESE

TABLE NO 25

Micrograms of Manganese per gram of dried Chinese Cabbage foliage

Medium		FTE level g/m^3				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	129a	171bc	178bcd	246g	221efg
New Zealand peat	pumice	155ab	190cde	209def	223efg	227fg

LSD P=0.05 31.3
P=0.01 41.9

Media with pumice as the inorganic fraction averaged more plant uptake of Mn than those media made with perlite. However, this difference between the media was not significant.

A significant effect of adding FTE 36 was observed, which resulted in higher Mn uptake from all treatments receiving FTE 36. With perlite as the inorganic substrate Mn uptake from treatments 1 & 2, or 3 & 4 were not significantly different. The treatments 0, 1 & 3 were significantly different. The highest uptake of Mn in perlite mixtures occurred with 300 g FTE 36/ m^3. In pumice based media the Mn uptake from treatments 1, 2 & 3 were not significantly different from each other, similarly, treatments 2, 3 & 4 were not significantly different from each other. Manganese uptake from treatments 1 & 4 were significantly different. Maximum uptake of Mn occurred with the highest level of FTE 36.

IRON

TABLE NO 26

Micrograms of Iron per gram of dried Chinese Cabbage foliage

Medium		FTE level(x100 g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	63.6a	69.2a	78.4a	73.2a	67a
New Zealand peat	pumice	87.2b	76.8a	71.2a	92.4b	72a

LSD P=0.04 19.7
P=0.01 26.5

Slightly more Fe was taken up by the plants grown in pumice based media rather than perlite based media. This increase was significant only in the treatments with nil FTE or 300g FTE 36/m^3. All other comparisons were not significant.

No significant effect of adding FTE 36 to either media was observed.

MEDIA EXTRACTS (Experiment 3)

COPPER

TABLE NO 27

Micrograms of EDTA-extractable Copper per gram of growing medium

Medium		FTE level (x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	11.8ab	17bc	23.8cd	29.2d	40.6e
New Zealand peat	pumice	8.8a	12.9ab	18.8bc	27.2d	38.9e

LSD P=0.05 7.9
P=0.01 10.9

No significant difference in extractable Cu between the two media was observed.

A highly significant effect of adding FTE 36 was recorded. Extractable Cu from treatments 0 & 1, 1 & 2, or 2 & 3 were not significantly different from each other, but treatments 3 & 4 were significantly different from each other. Overall there was an increase in extractable Cu with increasing FTE level.

ZINC

TABLE NO 28

Micrograms of EDTA-extractable Zinc per gram of growing medium

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	38.6d	41.2e	47.2f	55.6g	91.8h
New Zealand peat	pumice	15.2a	16.8a	23.3b	29.8c	39.8de

LSD P=0.05 5.7
P=0.01 7.7

A highly significant difference in the extractable Zn between the two growing media was observed. Where perlite was the inorganic fraction, significantly more Zn was extractable, compared with that from pumice amended media, irrespective of FTE level.

As FTE 36 level was increased, extractable Zn increased correspondingly. In perlite mixtures all treatments were significantly different from each other. In pumice mixtures all treatments, except 0 & 1 were significantly different from each other.

MANGANESE

TABLE NO 29

Micrograms of EDTA-extractable Manganese per gram of growing medium

Medium		FTE level(x100g/m^3)				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	10.5a	21.4b	27.6bc	34.6c	44.8d
New Zealand peat	pumice	23.4b	28.6bc	43.4d	49.4de	54e

LSD P=0.05 7.2
P=0.01 10.1

EDTA extracted more Mn from pumice based media than from perlite based media. Significant differences were observed between the media in all treatments, except where the applied FTE level was 100 g/m^3 (it was nearly significant at 5% level).

Frit added to both media increased the EDTA-extractable Mn. In perlite based media all treatments, except 1 & 2 were significantly different from each other. In pumice based media the Mn extractable from treatments 0 & 1, 2 & 3, or 3 & 4 were not significantly different from each other.

IRON

TABLE NO 30

Micrograms of EDTA-extractable Iron per gram of growing medium

Medium		FTE level 100 g/m^3				
Organic	Inorganic	0	1	2	3	4
New Zealand peat	perlite	194.4a	192.8a	205.6a	195.2a	208
New Zealand peat	pumice	442b	442b	482b	476b	464b

LSD P=0.05 44.9
P=0.01 60.3

A highly significant difference in the level of extractable Fe between the two media was observed. In pumice based substrates significantly more Fe was extractable compared with that from perlite based media.

No significant effect of adding FTE 36 to either medium was noted.

Discussion

Copper levels in Chrysanthemum, Sorghum and Chinese Cabbage follow the same general trend, with increasing frit application foliar Cu levels increased, although the response of each species was slightly different (see fig. 4,5,6).

In the absence of added FTE 36, Cu levels derived from NZP/Per and NZP/Pum were similar; this could suggest that Cu availability from each medium was essentially the same in these mixtures. As the level of Frit 36 in the medium was increased, the extractable Cu increased in an essentially linear manner with no significant difference occurring between NZP/Pum and NZP/Per at equal frit levels. Extractable Cu was always slightly higher from NZP/Per than from NZP/Pum (see fig 7). This observation is in accord with previous experiments.

The three test plants used appeared to differ in their capacity for Cu uptake from the two media. Chrysanthemum plants (see fig 4) show higher levels of foliar Cu on NZP/Per than NZP/Pum. This trend is repeated clearly by Chinese Cabbage (fig 6) and less clearly by Sorghum (fig 5). This trend may suggest that Cu availability from FTE 36 is higher in NZP/Per than in NZP/Pum.

In fig. 4 it is noted that plant response in the two media is different. The decrease in foliar Cu level from the NZP/Pum medium with the highest frit level was not expected. An interaction between Cu and another element (possibly Mn or Fe) in the medium may have effected some control on Cu levels. Alternatively, the variation may have arisen through the effect of non uniform frit distribution on Cu availability within the medium, or through the involvement of an undefined factor.

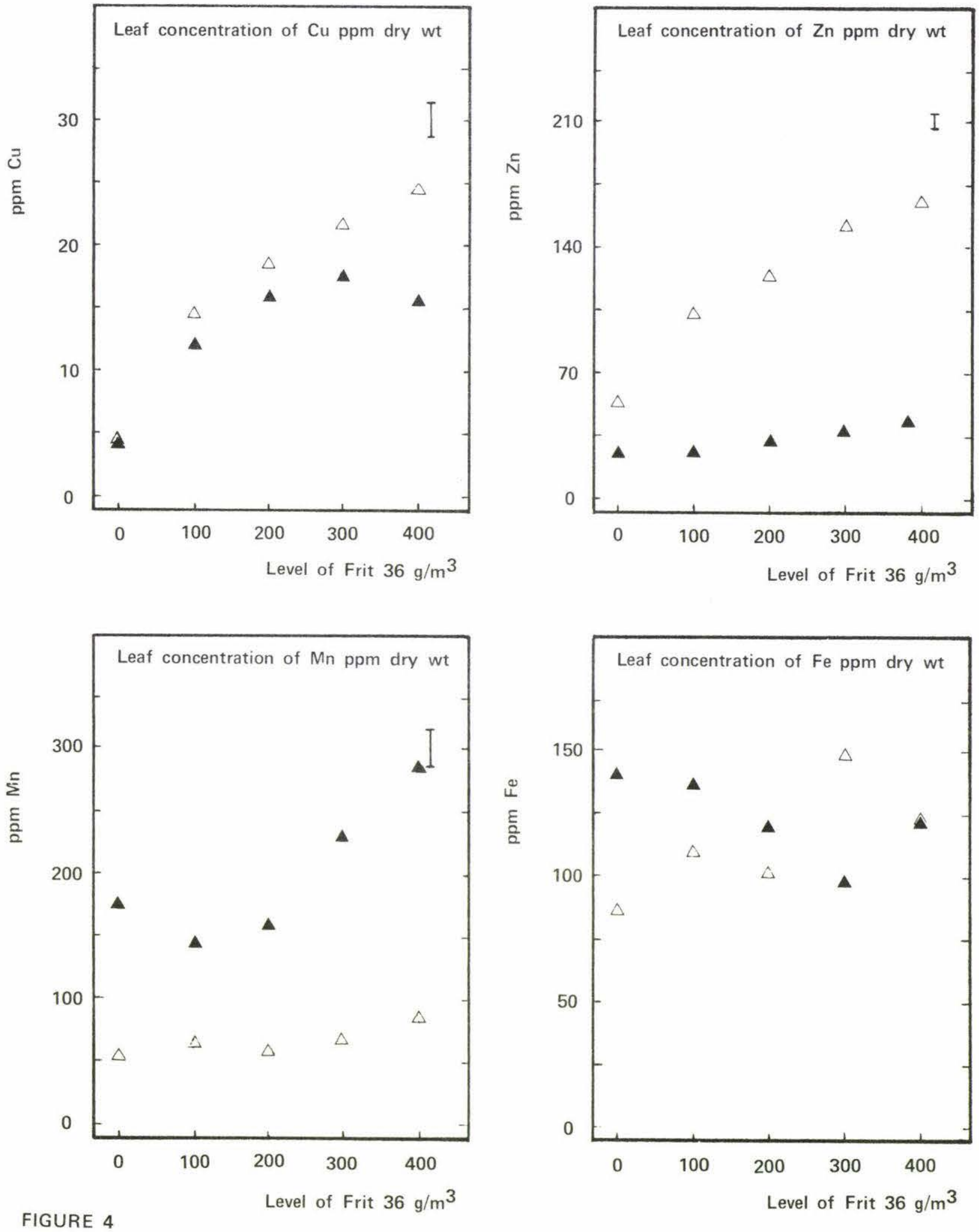


FIGURE 4

Influence of growing medium and level of Frit 36 on the concentration of micronutrients in *Chrysanthemum 'Nob Hill'.*

△ = New Zealand Peat/Perlite ▲ = New Zealand Peat/Pumice I LSD(0.05)

Copper levels in Chrysanthemum foliage in the nil FTE treatments were less than the critical values proposed by Nelson (1971), yet copper deficiency symptoms were not observed (see plate 6). Foliar Cu levels were high (with FTE 36, where used in excess of $100g/m^3$) relative to recommendations by Lunt et al (1964) but never as high as the 35ppm Woltz (1956) considered optimal.

Sorghum plants did not respond to frit addition with the same clarity noted with Chrysanthemum and Chinese Cabbage plants. This may be attributable in part to the fact that not all plants in a seedline absorb nutrients equally, thus increasing variability(Munson, 1969).

The Cu requirement of Sorghum is relatively low, 2-7ppm (Lockman, 1972), this appeared to be satisfied by the medium without FTE addition, or possibly from seed reserves. The increase in foliar Cu level resulting from increased FTE level may have been expected to follow a linear rather than asymptotic response(Bates, 1971). The results observed here show a distinct plateau in the region 12-14 ppm Cu. The higher level of FTE required in NZP/Pum to attain a similar foliar level of Cu may have arisen because of a lower Cu availability on NZP/Pum. Alternatively if the ideal plant response to frit addition was linear in both media, then the most discordant Cu level determined occurred in foliage from NZP/Per with FTE level $100g/m^3$. It was noted that the Fe levels from the same treatment were lower than all other treatments. Foliar contamination is considered unlikely to produce errors of this nature.

An interaction between Cu and Fe as reported by Cheshire et al (1967) may have produced this result, but variation in the medium could also have produced the results observed, despite the efforts made to ensure each treatment was accurately prepared and thoroughly mixed.

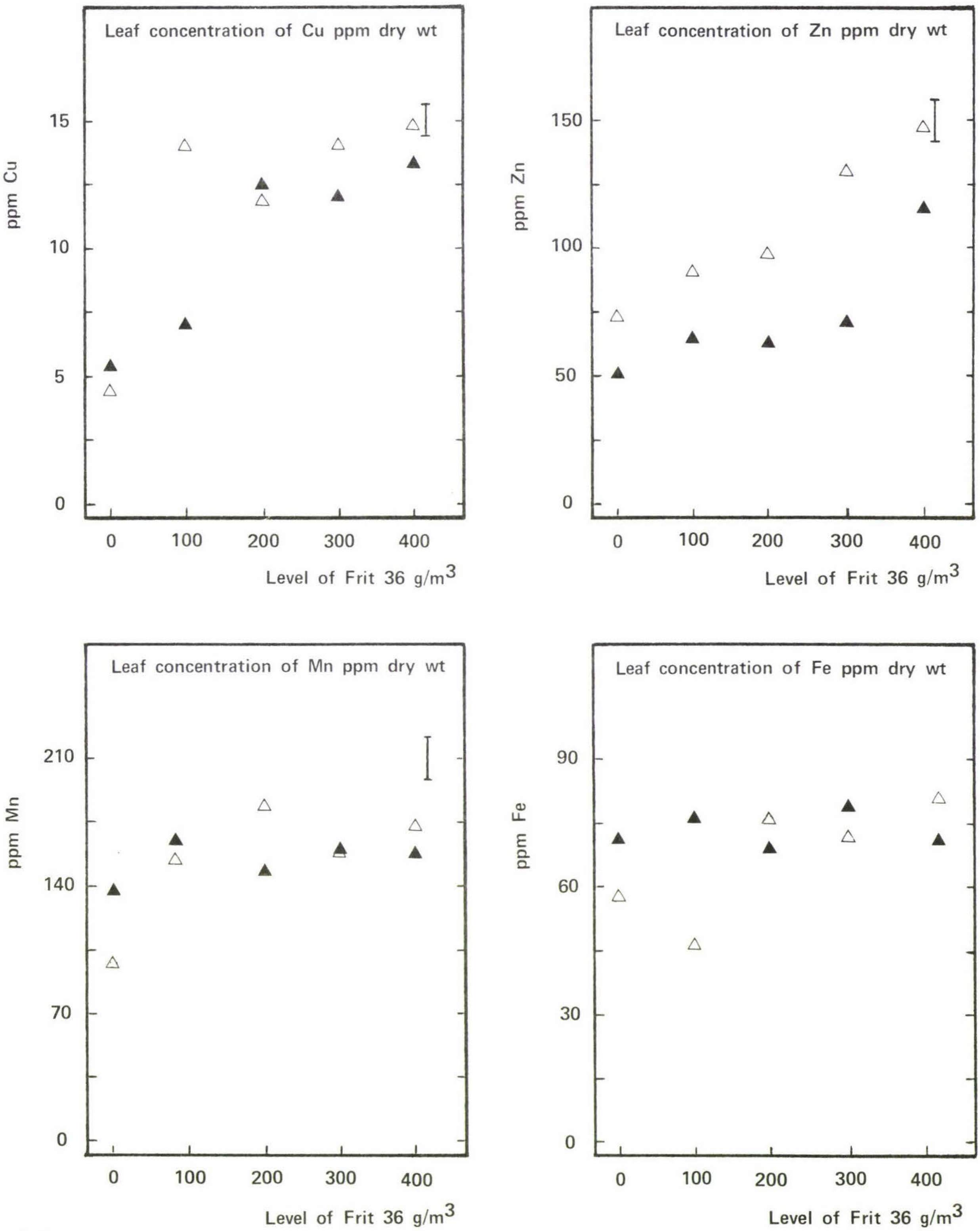


FIGURE 5

Influence of medium and level of Frit 36 on the concentration of micronutrients in *Sorghum 'RS 610'.*

△ = New Zealand Peat/Perlite ▲ = New Zealand Peat/Pumice I LSD(0.05)

The foliar Cu removed by Chinese Cabbage from the two media separated NZP/Pum and NZP/Per more distinctly than did Chrysanthemum, Sorghum or the EDTA extraction. Chinese Cabbage appeared to absorb more Cu from NZP/Per than from NZP/Pum. The smaller increase in foliar Cu noted on NZP/Pum relative to NZP/Per is probably attributable to lower Cu availability on NZP/Pum as may have been inferred from preliminary work.

Foliar Zn levels in all three test plants show significantly higher uptake from NZP/Per than from NZP/Pum (see figs 4, 5, 6). Similarly, EDTA-extractable Zn is higher from NZP/Per than from NZP/Pum (see fig. 7). The extractable Zn from the mixtures follows a similar pattern to that of foliar Zn in Sorghum and Chinese Cabbage. Chrysanthemum plants appear to differentiate between the NZP/Per and NZP/Pum more distinctly than the other test plants or the extractant.

The relatively constant difference in the level of foliar Zn for both Sorghum and Chinese Cabbage in the two media was matched by a similar difference in EDTA extractable Zn.

Chrysanthemum plants appear to experience more difficulty in absorbing Zn from NZP/Pum relative to NZP/Per as only a small increase in foliar Zn occurred with increased frit application. A similar response from Chrysanthemum plants was detected in Experiment 2. The net observed effect is that NZP/Per appears to supply more plant available Zn than NZP/Pum.

The isolation of the Zn sorption and release characteristics of each medium could readily be clarified using a radioactive tracer to estimate the extent of Zn uptake from the medium and Zn retention by the medium. These particular experiments have not quantified these factors. The levels of foliar Zn estimated in Chrysanthemum and Sorghum are in the range considered normal by Lunt et al (1964) and Lockman (1972). No recommendations are available for Chinese Cabbage, however the values are of a

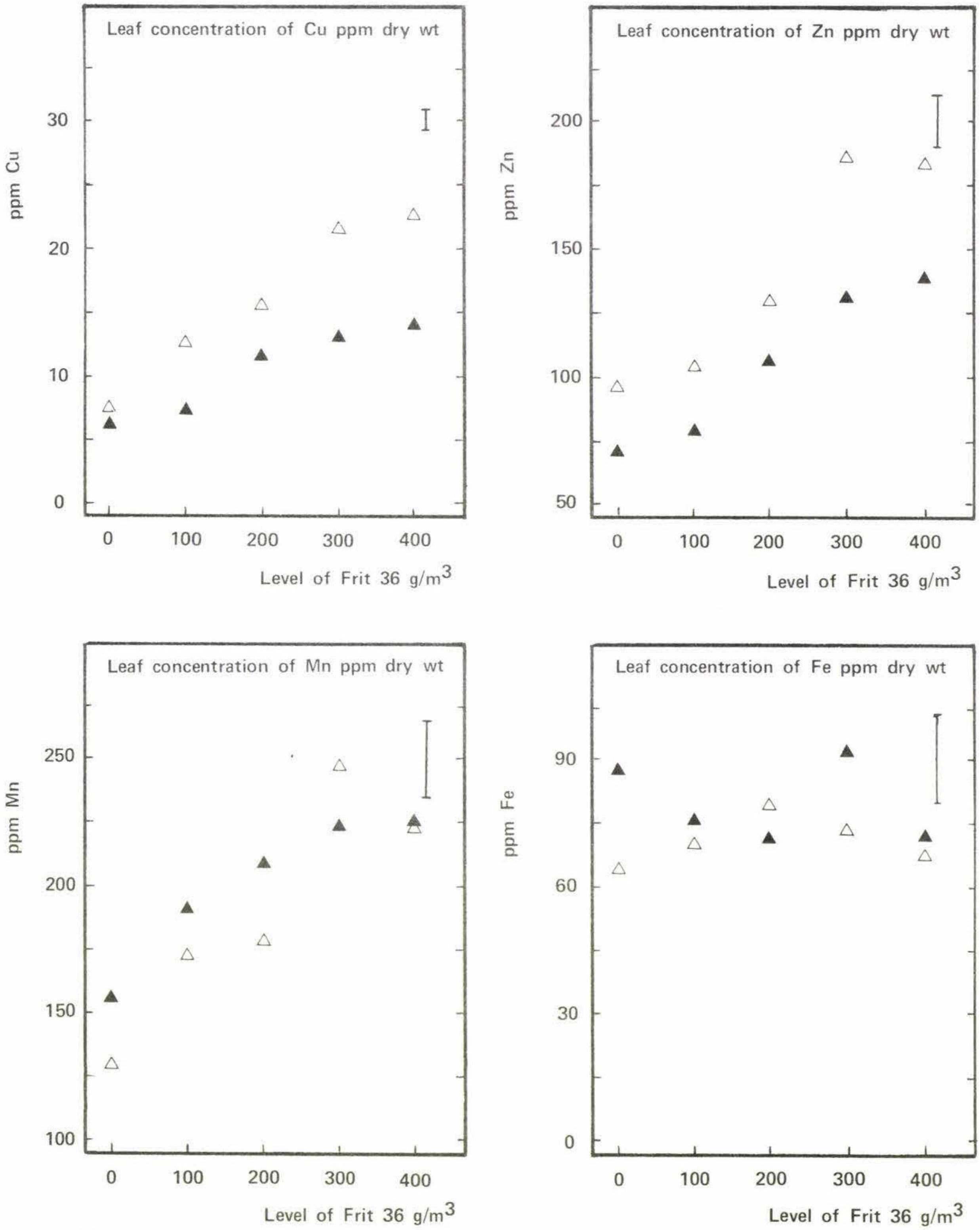


FIGURE 6

Influence on medium and level of Frit 36 on the concentration of micronutrients in Chinese Cabbage.

△ = New Zealand Peat/Perlite ▲ = New Zealand Peat/Pumice I LSD(0.05)

similar magnitude to those assessed for Sorghum and Chrysanthemum and probably adequate for normal growth.

The foliar Mn in Chrysanthemum plants readily differentiated between NZP/Per and NZP/Pum. The Mn extractable (with EDTA) from each medium produced a similar trend but the difference was less marked. Manganese availability from NZP/Pum appears to have been higher in the nil FTE treatment than expected. Chrysanthemum plants registered a relatively high Mn level in this treatment, which appears to correspond with the higher level of EDTA extractable Mn. This unexpected result could have arisen from a small inconsistency in the medium rather than a difference in individual plant response; as all these Chrysanthemum plants were propagated from a single clone which would be expected to respond uniformly.

As NZP/Per would have less capacity to adsorb Mn than NZP/Pum (based upon preliminary experiments); the observed response to the addition of FTE 36 was less than might have been predicted (see fig. 4). This suggests a factor from within the NZP/Per medium may reduce the plants capacity to absorb Mn.

Neither Sorghum or Chinese Cabbage produced significant differences in foliar Mn levels between NZP/Per and NZP/Pum. Each plant responded in a similar manner in each medium, but overall a more marked response to added FTE 36 was observed with Chinese Cabbages as the test plant. The Mn requirement of Sorghum appears readily satisfied, and thereafter further uptake of Mn may be restricted. Lockman (1972) reported that Sorghum has a low minimum Mn requirement (8ppm), but the plant was tolerant of much higher Mn levels.

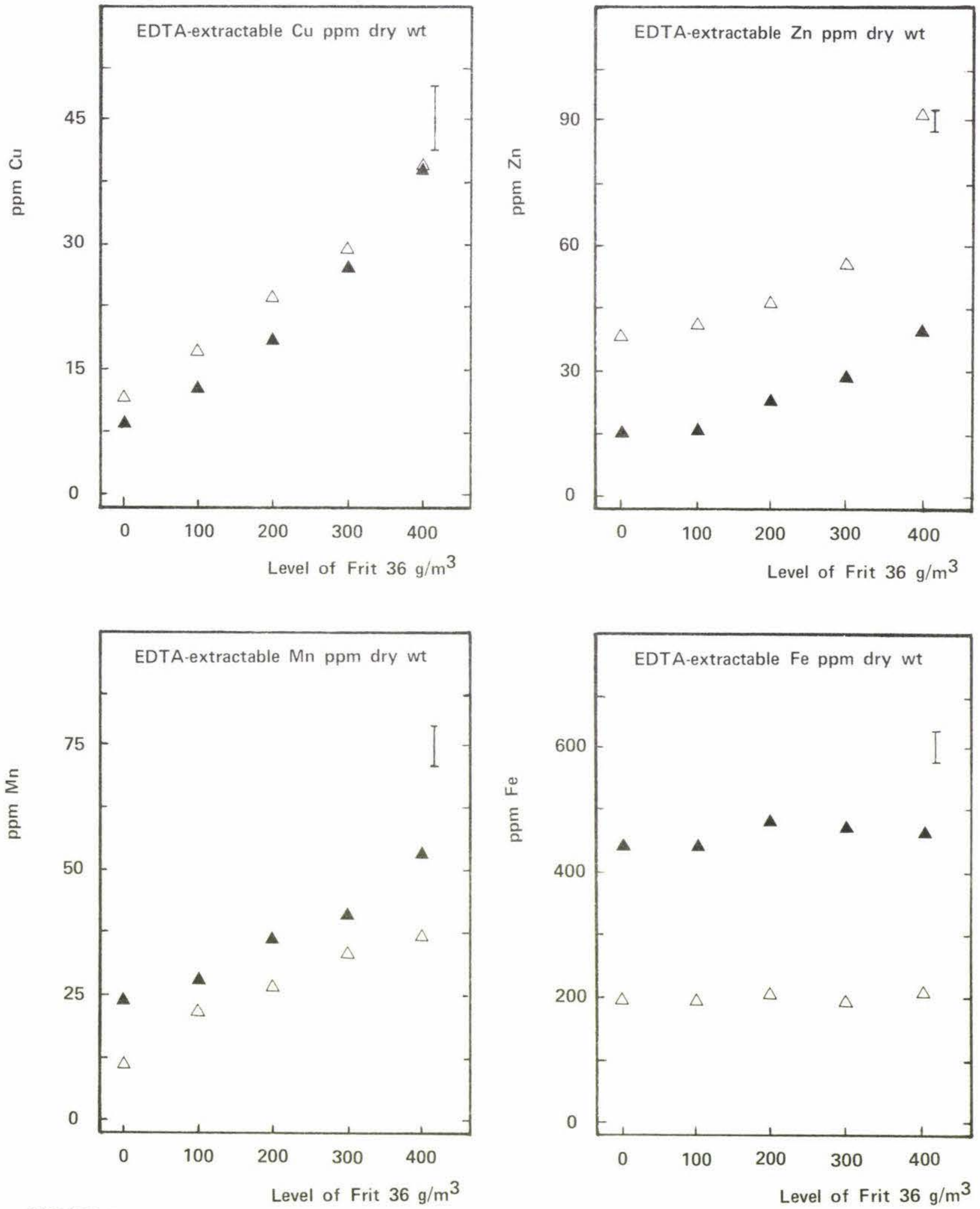


FIGURE 7

Influence of growing medium and level of Frit 36 on EDTA-extractable micronutrients.

△ = New Zealand Peat/Perlite ▲ = New Zealand Peat/Pumice I LSD(0.05)

Foliar Fe in plants grown in NZP/Pum was slightly higher than that from NZP/Per, for all three test plants. EDTA extracted more than twice as much Fe from NZP/Pum as from NZP/Per. This could suggest that a large proportion of the Fe extracted the NZP/Pum is not immediately available to plants. The disparity between plant Fe and extractable Fe is not unexpected as the availability of Fe is dependent on many factors apart from its extractability. Some of them are inherent in the plant. "It is doubtful that any Fe soil test will be very reliable until more of these factors are understood and their actions accounted for," Cox and Kamprath (1972).

No significant increase in plant Fe was discerned following an increase in FTE level, this is in accordance with work by Wynd and Stromme (1953); Rhoads et al (1956) and Smilde (1975) and at a variance with results published by Bunt (1971).

The iron levels in both Chinese Cabbage and Sorghum foliage were of a similar magnitude. Sorghum Fe levels were on the low side of the 65-100ppm minimum recommendation by Lockman (1972). Despite the low Fe levels, interveinal chlorosis was not observed in the plants with the lowest Fe levels. The slightly paler colour of foliage from NZP/Per relative to NZP/Pum did not appear related to total Fe levels in each plant. Lunt et al (1964) considered Fe levels in excess of 100ppm were present in normal Chrysanthemum leaves and levels of 80ppm or less could produce chlorotic foliage. The observed foliar levels of Fe from NZP/Per tended to be lower than those from NZP/Pum, but were close to 100ppm (see fig. 4). The incidence of foliar chlorosis did not increase with lower levels of Fe. The slightly lower pH of the NZP/Per medium (pH 4.8) relative to NZP/Pum (pH 5.2) would have been expected to increase Fe availability, but this was not reflected in increased Fe uptake.

The aluminium levels measured in Chrysanthemum foliage suggests that Al is relatively more available from NZP/Pum than from NZP/Per (see table 18). This supports preliminary experimental results where Al was more extractable from pumice than from perlite. However, these results are in marked contrast to reports by Green (1968) and Gogue and Sanderson (1975) where higher levels of Al were measured in foliage from plants grown in a medium based on perlite.

Green (1968) considered Al was differentially removed from the aluminium tetrahedra present in perlite. The results reported here do not support this assertion.

The phosphate extractable from NZP/Per was significantly higher than that from NZP/Pum (see table 53). In excess of 2000ppm P was detected in each medium prior to use, without peat in the medium this P level could have been expected to produce Fe chlorosis in all test plants (Sims and Gableman, 1956). However, the presence of humic and fulvic acids in the peat appears to increase a plants' capacity to utilise Fe in the presence of high P levels (Sims and Gableman, 1956; Schnitzer and Poapst, 1967; Schnitzer, 1969).

The increase in micronutrient content of foliage following increased frit application is in accordance with Roll-Hansen's (1975) experience with FTE 36. Application of FTE 36 even at relatively high rates did not prevent the random expression of foliar chlorosis by Chrysanthemum plants grown in NZP/Per (see plate 6). Plants growing in NZP/Pum only showed foliar chlorosis when growing adjacent to chlorotic plants growing in NZP/Per. This could suggest a soluble material is transferred from NZP/Per to NZP/Pum via the capillary pad and interferes with Fe utilisation without reducing Fe uptake.

Dissolution of superphosphate particles in the medium may produce localised areas of very low (1-2) pH (Huffman and Taylor, 1963); also slight dissolution of perlite in dilute acid has been reported by the Perlite Institute (1974). The very low localised pH coupled with the slight dissolution of perlite may allow the release of a material which alters Fe ultilisation within the plant (Olsen, 1972). Pumice may react in a similar manner, but it is anticipated that since its formation weathering and leaching could have removed the majority of the loosely held surface material.

All the foliage of Sorghum when grown in NZP/Per was a lighter green than that observed in NZP/Pum (see plate 7). Similarly Chinese Cabbage showed slightly chlorotic areas in foliage from plants grown in NZP/Per. Foliage from NZP/Pum was darker green by comparison (see plate 8).

It would appear probable that some factor derived from the perlite based medium may be affecting the internal ultilisation of Fe, which could generate the observed differences. This would appear more likely than a factor acting solely to impair Fe uptake.

The higher level of extractable P measured in NZP/Per relative to NZP/Pum may have decreased the plants internal Fe/P ratio and restricted Fe utilisation without altering Fe uptake as reported by De Kock (1955, 1958).

Alternatively, the cause of the observed chlorosis may as yet be unresolved. Estimation of micronutrient activity and availability within the plant using a biochemical assessment may allow the development of a more rational basis for interpretation of nutrient levels within plants than that allowed by the use of whole leaf samples as used in these experiments (Brown and Hendricks, 1952; Palmer et al, 1963; Dwivedi and Randhawa, 1974; Davies and Winsor, 1971).

EXPERIMENT FOUR

Chrysanthemum 'Nob Hill' (Experiment 4A) and Sorghum 'RS 610' (Experiment 4B) were grown in perlite or pumice with the standard nutrient supply, except half the normal lime requirement was used. Fritted trace elements FTE 36 and FTE 503 were applied at 0 and $100 g/m^3$.

Experiment 4 A

Non-chlorotic Chrysanthemum plants were planted in the growing medium 31 July and allowed to reach a height of about 50 cm before harvest on 10 October. After 1 month the Chrysanthemum plants in the pumice medium were still non-chlorotic, but those plants in the perlite substrate had produced foliage with a vivid interveinal chlorosis. All new leaves produced by these plants after this time were chlorotic (see plate 9), whilst the oldest 'original' leaves remained green and apparently healthy. One month prior to harvest, all plants growing in pumice substrate possessed healthy green foliage. However, all the plants grown in the perlite medium were highly chlorotic and approximately one third of the youngest mature leaves possessed some marginal necrosis, although no pathogen was isolated.

At harvest, the leaves from all pumice treatments were non-chlorotic, irrespective of FTE source. The recently-produced chlorotic leaves from perlite media were longer and more flattened, compared with leaves from pumice treatments. The nil FTE and FTE 36 treatments were comparable, but the FTE 503 treatment produced the most highly chlorotic foliage, as depicted in a range of representative leaves (see plate 9).

After the removal of samples for foliar analysis, the following aqueous solutions were applied to the remaining leaves on the chlorotic plants: (a) 1% w/v Fe-EDTA

(b) 1% w/v $FeSO_4.7H_2O$

(c) 1% w/v $CuSO_4.5H_2O$

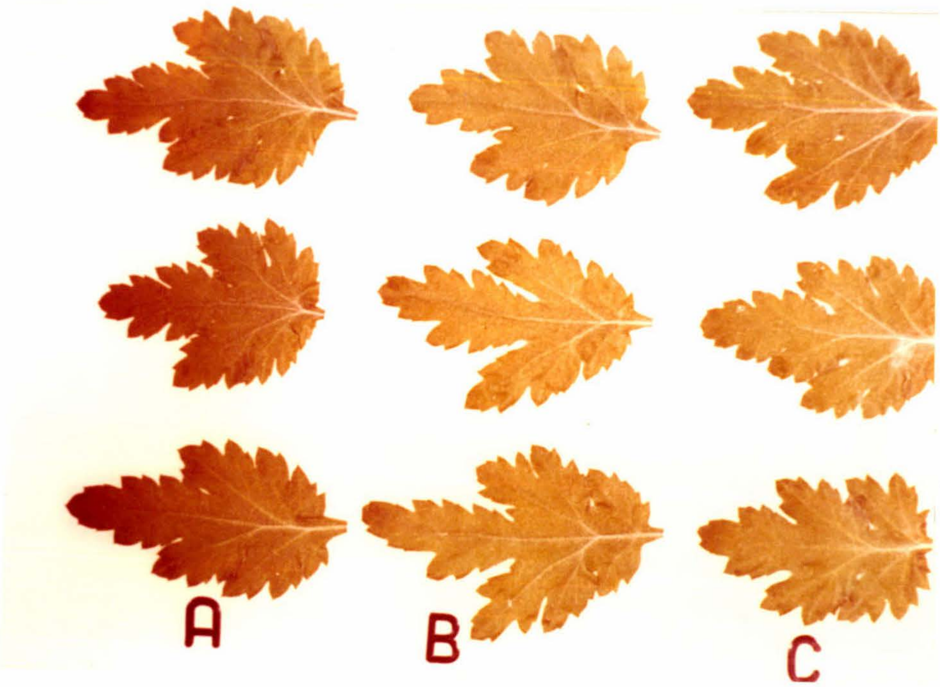
(d) equal amounts of b & c combined

(e) distilled water control.

No regreening of mature chlorotic tissue, relative to the control (e) was observed after 14 days. Extensive scorching of foliage dipped into b, c and d, occurred. Application of only (a) to chlorotic expanding leaves appeared to increase the green pigmentation relative to controls.

After the experiment was terminated, a visual assessment of root growth was made. No FTE treatment effects were observed. The white roots of Chrysanthemum plants grown on pure perlite were slightly coarser and possessed less lateral development than the brown roots from plants grown in pumice. The ash of washed roots from perlite media effervesced more strongly with acid, compared with roots from a pumice media.

(i)



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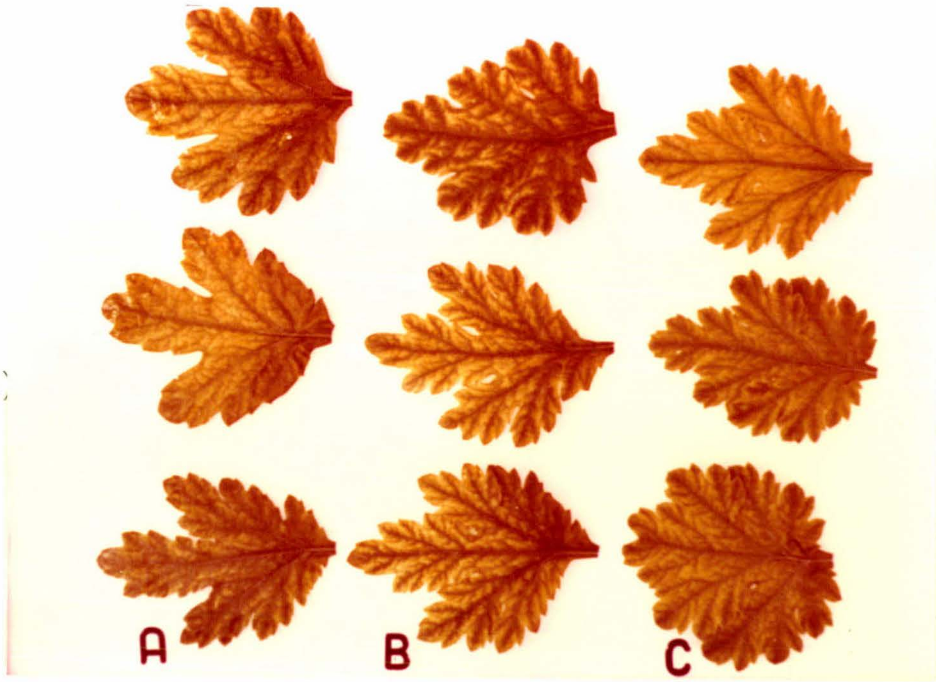


Plate 9 Foliage of *Chrysanthemum* 'Nob Hill' plants grown in (i) pumice and (ii) perlite with (A) no Frit added, (B) Frit 503 added, or (C) Frit 36 added to the growing medium

PLANT ANALYSIS

COPPER

TABLE NO 31

Micrograms of Copper per gram of dried Chrysanthemum foliage

	FTE source		
Medium	Nil	503	36
Perlite	5.8a	29.8d	27.4d
Pumice	4.2a	12.5c	8.8b

LSD P=0.05
P=0.01

Where perlite was the growing medium, more plant uptake of Cu occurred compared with a pumice medium. Significantly more Cu uptake occurred where the FTE were added, but not when FTE was absent.

A highly significant effect of adding FTE to the media was observed. Where perlite was the substrate, no significant differences in Cu uptake were observed between the two frits. Both frits significantly increased plant uptake relative to the nil FTE treatment. When pumice was the growing medium, then both frits appeared to significantly increase plant uptake of Cu relative to the nil FTE treatment. Plant uptake of Cu from media with FTE 503 was significantly greater than that from media with FTE 36.

ZINC

TABLE NO 32

Micrograms of Zinc per gram of dried Chrysanthemum foliage

	FTE source		
Medium	Nil	503	36
Perlite	36.48	199.6c	76.4b
Pumice	28a	71.6b	29.8a

LSD P=0.05 11.6
P=0.01 15.8

Perlite treatments appeared to supply more Zn for plant uptake than pumice. Differences in Zn uptake were only significant after the addition of FTE.

Application of FTE increased plant uptake of Zn, irrespective of media; more Zn uptake occurred where FTE 503 was used, compared with FTE 36. For a perlite medium, Zn uptake with FTE 503 was significantly higher than with FTE 36. Zinc uptake with either frit added to the medium was significantly higher than the nil FTE treatment. Where pumice was the medium, plant uptake of Zn from the FTE 503 treatment was significantly higher than that from the nil FTE or FTE 36 treatments, neither of these was significantly different from each other.

MANGANESE

TABLE NO 33

Micrograms of Manganese per gram of dried Chrysanthemum foliage

	FTE source		
Medium	Nil	503	36
Perlite	32a	142c	100b
Pumice	94b	160d	141.6c

LSD P=0.05 15.6
P=0.01 21.3

Significantly more plant uptake of Mn occurred from a pumice medium relative to that from perlite medium irrespective of FTE source.

In both media, FTE 503 appeared to supply significantly more Mn for plant uptake compared with FTE 36 which also appeared to supply significantly more Mn than the nil FTE treatments.

IRON

TABLE NO 34

Micrograms of Iron per gram of dried Chrysanthemum foliage

	FTE source		
Medium	Nil	503	36
Perlite	78a	74a	115.6b
Pumice	124.8b	82a	110.8b

LSD P=0.05 22.3
P=0.05 30.5

Over-all treatments, relatively more Fe uptake occurred from pumice media than from perlite media. Significantly more Fe uptake occurred from pumice media relative to perlite media prior to adding FTE, but there was no significant difference observed after adding either frit.

Where perlite was the medium, addition of FTE 36 significantly increased Fe uptake, relative to treatments with nil FTE or FTE 503 additions, which were not significantly different from each other.

Where pumice was the medium, there was no significant difference in uptake from the nil FTE or FTE 36 treatments. However, relative to these treatments the addition of FTE 503 significantly reduced Fe uptake into these leaves.

ALUMINIUM

TABLE NO 35

Micrograms of Aluminium per gram of dried Chrysanthemum foliage

	FTE source		
Medium	Nil	503	36
Perlite	21ab	32bc	11a
Pumice	17ab	40c	14a

LSD P=0.05 17.5
P=0.01 23.8

No significant differences in Al uptake between the two media were observed, although Al appeared to be slightly more available in the pumice medium compared with that from perlite.

Curiously, the addition of FTE 503 increased foliar Al levels relative to the nil FTE treatment. In contrast, the addition of FTE 36 appeared to reduce foliar Al levels. This difference between the two frits was significant.

Experiment 4 B

Six Sorghum plants were planted in each pot and allowed to grow from 8 August until 17 October. One month from planting, relatively more vegetative growth had been produced by all pumice treatments, compared with perlite treatments. This trend was maintained until harvest and confirmed by the wet and dry weight determinations. The youngest leaves in the perlite treatments were showing incipient interveinal chlorosis, irrespective of the FTE source. Sorghum plants from all pumice treatments were a healthy green at this stage.

By 15 September, foliar chlorosis in perlite treatments was more severe. The leaves on these plants were also more siliceous and abrasive than those from pumice treatments. The leaf lamina from all pumice treatments were a uniform green, but a small purple margin was becoming apparent on the leaf margins of all these treatments.

At sampling time, interveinal chlorosis was more pronounced on perlite treatments, particularly when the frit used was FTE 503. The narrowest and smallest leaves were produced by this treatment. Marked chlorosis was present in the nil FTE treatment, but significantly more growth was produced when compared with that from the FTE 503 treatment. The FTE 36 treatment exhibited the least chlorosis and from the perlite medium also produced the largest wet and dry weights. The purple leaf margin was most pronounced on the pumice treatments and not observed at all in perlite treatments. Leaf colour was similar throughout the pumice medium, the largest leaves were produced in the pumice medium with added FTE 36 (see plate 10).

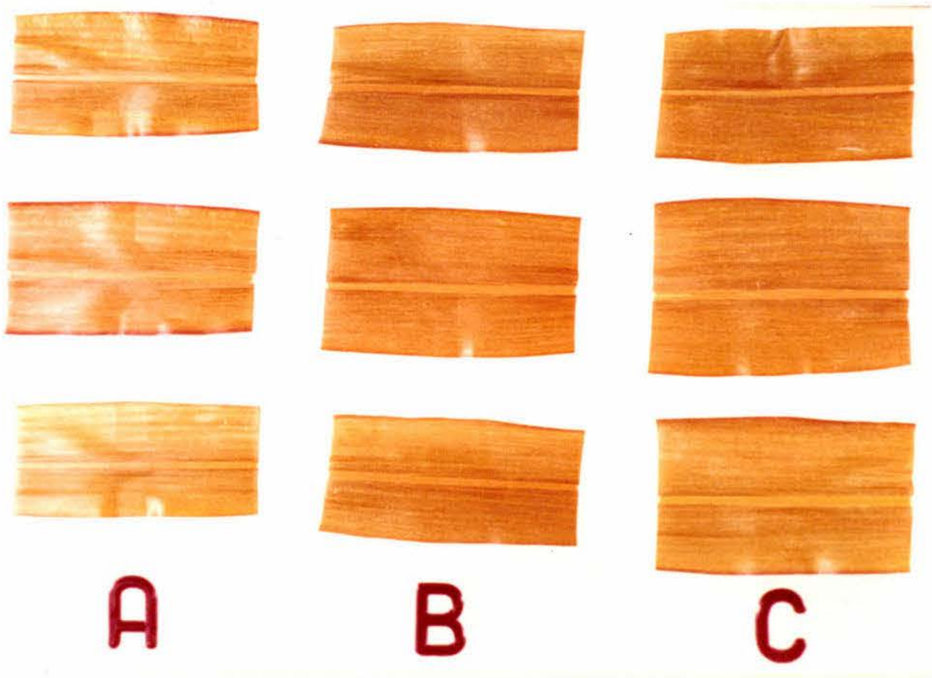
After harvesting 5 plants from each pot, aqueous solutions of 2.5% or 0.5% w/v $FeSO_4.7H_2O$ were applied to selected leaves of each treatment. Within 3 days, the 2.5% $FeSO_4$ proved to be phytotoxic;

when it was applied as a dip more than half of the leaf was blackened by the treatment. Application of 0.5% $FeSO_4$ produced only small phytotoxic spots along the interveinal area of each leaf. After 7 days, visible regreening had occurred on all the perlite treatments, but no change was visible on pumice treatments. Spot application of both $FeSO_4$ concentrations promoted local regreening of chlorotic tissue, but a phytotoxic reaction was still observed (see plate 11).

After the experiment was terminated, root growth in each medium was examined. More root growth was observed in a pumice medium, compared with that in a perlite medium. Within each media treatment, least root growth occurred where FTE 503 was used and the most root growth occurred with applied FTE 36.

After ashing, the samples were dissolved in acid. This reaction was more vigorous from plant samples from a perlite medium than from pumice medium. There were 3.5-4 times more acid-insoluble residues from perlite treatments, relative to pumice treatments.

(i)



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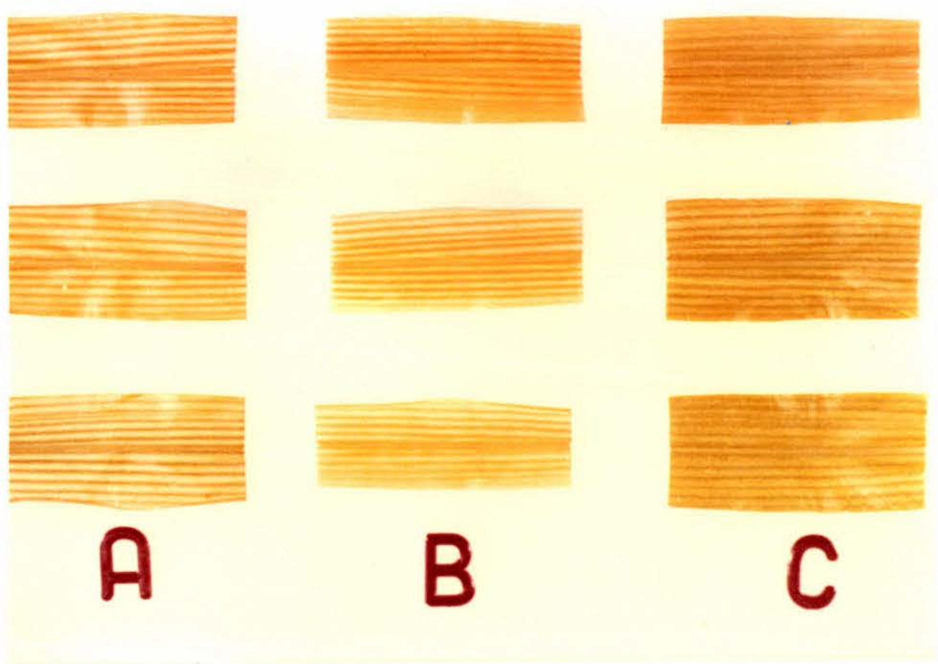

Plate 10 Foliage sections of Sorghum 'RS610' plants grown in (i) pumice and (ii) perlite with (A) No Frit added (B) Frit 503 added or (C) Frit 36 added to the growing medium

PLANT ANALYSIS

COPPER

TABLE NO 36

Micrograms of Copper per gram of dried Sorghum foliage

	FTE source		
Medium	Nil	503	36
Perlite	5.8b	12.6e	9.6cd
Pumice	1.4a	10.8de	8.3c

LSD P=0.05 2.0
P=0.01 2.8

Plant uptake of Cu was higher from perlite based media than from pumice based media. Significantly more Cu uptake occurred from perlite in the Nil FTE and FTE 36 treatments. The difference in Cu uptake from perlite and pumice when FTE 503 was added followed the same trend, but was not statistically significant.

A highly significant effect of adding FTE to each media was observed. FTE 503 appeared to supply significantly more Cu than FTE 36, which also appeared to supply more available Cu than the nil FTE treatments in both media.

ZINC

TABLE NO 37

Micrograms of Zinc per gram of dried Sorghum foliage

	FTE source		
Medium	Nil	503	36
Perlite	44.2b	140.8e	60.6c
Pumice	20.6a	78.2d	32.4ab

LSD P=0.05 12.2
P=0.01 16.7

All the perlite media appeared to release significantly more Zn for plant uptake than pumice media.

When FTE s were applied, increased Zn uptake occurred relative to the nil FTE treatment irrespective of media. FTE 503 appeared to supply significantly more available Zn than FTE 36, when used with either medium. With a perlite substrate, FTE 36 increased Zn uptake above the nil FTE treatment. No significant difference between these two treatments was noted when pumice was the medium, although the differences followed the same trend as for perlite.

MANGANESE

TABLE NO 38

Micrograms of Manganese per gram of dried Sorghum foliage

	FTE source		
Medium	Nil	503	36
Perlite	25.2a	157d	57.6bc
Pumice	42.4ab	160d	67.2c

LSD P=0.05 19.8
P=0.01 20.1

Where pumice was the medium Sorghum plants found the Mn more available than that from the perlite medium, irrespective of FTE level. However none of these differences were significant.

Addition of either frit to the media significantly increased foliar Mn levels above those from nil FTE treatments. FTE 503 supplied significantly more Mn than FTE 36 in either medium.

IRON

TABLE NO 39

Micrograms of Iron per gram of dried Sorghum foliage

	FTE source		
Medium	Nil	503	36
Perlite	44a	44.4a	42.8a
Pumice	56b	55.2b	56b

LSD P=0.05 4.2
P=0.01 4.8

Significantly less Fe uptake occurred from perlite media than from pumice media.

No significant frit effects were observed within either media. The Fe uptake from all FTE treatments was very similar.

ALUMINIUM

TABLE NO 40

Micrograms of Aluminium per gram of dried *Sorghum* foliage

	FTE source		
Medium	Nil	503	36
Perlite	56abc	61bc	52ab
Pumice	56abc	68c	47a

LSD P=0.05 13.1
P=0.01 18.7

No significant difference in Al uptake between the two media was observed.

The application of frits was observed to have a small effect on Al uptake by *Sorghum*. For both media, uptake of Al was highest where FTE 503 was used, compared with the other treatments. Application of FTE 36 appeared to reduce Al uptake below that of the nil FTE treatment. No significant differences in Al uptake were detected where perlite was the medium, but in a pumice substrate, the Al uptake from the FTE 503 treatment was significantly greater than that from the FTE 36 treatment.

MEDIA EXTRACTS (Experiment 4).

COPPER

TABLE NO 41

Micrograms of EDTA-extractable Copper per gram of growing medium

	FTE source		
Medium	Nil	503	36
Perlite	4.3ab	11d	16.9e
Pumice	3.0a	5.0a	7.5c

LSD P=0.05 1.7
P=0.01 2.3

The perlite medium provided more extractable Cu than pumice medium, irrespective of FTE source. Significant differences between the two media were only achieved after adding FTE 503 or FTE 36.

A highly significant effect of adding frit was observed irrespective of the media. Significantly more Cu was extracted from FTE 36 treatments than from FTE 503, which also supplied significantly more Cu than the nil FTE treatments for both media.

ZINC

TABLE NO 42

Micrograms of EDTA-extractable Zinc per gram of growing medium

	FTE source		
Medium	Nil	503	36
Perlite	92.4b	192.2d	146.8e
Pumice	23.6a	30.0a	38.4a

LSD P=0.05 22.8
P=0.01 31.1

The perlite growing medium appeared to supply significantly more extractable Zn than pumice, irrespective of the FTE source.

The addition of frits to the medium increased the extractable Zn. In perlite, FTE 503 supplied significantly more extractable Zn than FTE 36, which also supplied significantly more than the nil FTE treatment. In the pumice medium, EDTA extracted more Zn from the treatments with added FTE than that from the nil FTE treatment. However, the difference between these treatments was not significant.

MANGANESE

TABLE NO 43

Micrograms of EDTA-extractable Manganese per gram of growing medium

	FTE source		
Medium	Nil	503	35
Perlite	18.4a	48.8e	26b
Pumice	29.2b	89.2d	32b

LSD P=0.05 8.5
P=0.01 11.7

The pumice substrate appeared to supply more extractable Mn than perlite, irrespective of FTE source. This difference between the two media was significant in the nil FTE and FTE 503 treatments, but not in the FTE 36 treatment.

The addition of frit to either medium increased the extractable Mn level. FTE 503 significantly increased the level of extractable Mn relative to either nil FTE or FTE 36,in both media. The addition of FTE 36 to the medium increased the level of extractable Mn relative to the nil FTE treatment. This increase was only significant in a perlite based medium.

IRON

TABLE NO 44

Micrograms of EDTA-extractable Iron per gram of growing medium

	FTE source		
Medium	Nil	503	36
Perlite	162.2a	178.4a	158.4a
Pumice	486b	510c	516c

LSD P=0.05 21.0
P=0.01 28.7

Pumice appeared to supply significantly more extractable Fe than the perlite media, irrespective of FTE source.

Added FTE did not significantly increase the level of extractable Fe from perlite treatments, but a significant increase was noted in the pumice treatments relative to the nil FTE treatment.

ALUMINIUM

TABLE NO 45

Micrograms of EDTA-extractable Alumium per gram of growing medium

	FTE source		
Medium	Nil	503	36
Perlite	370ab	354a	394b
Pumice	488c	512c	517c

LSD P=0.01 30.7
P=0.05 41.9

Significantly more Al was extractable from the pumice than from perlite.

No significant frit effects were observed.

Discussion

Foliar Cu levels in *Chrysanthemum* and *Sorghum* were higher in all treatments with perlite as the medium instead of pumice.

In the nil FTE treatment Cu availability to *Sorghum* was significantly higher from a perlite medium than from pumice. A similar trend was noted with *Chrysanthemum*, but the difference was not significant.

Where either frit was added to each medium Cu levels in *Chrysanthemum* plants were significantly higher in perlite than in pumice, although *Sorghum*'s foliar Cu followed the same trend there was no significant difference in the levels derived from either medium.

This could suggest that *Chrysanthemum* plants have only a limited capacity to remove Cu from the unamended medium, but Cu uptake occurs readily from frits, especially in perlite media. Foliar Cu levels in excess of normal requirements may have been achieved with the $100g/m^3$ FTE used, according to Reuther and Labanauskas (1966).

In contrast to *Chrysanthemum*, *Sorghum* plants appear to show a marked capacity to remove Cu from perlite relative to pumice in the absence of FTE, but when frit is added, the difference in foliar Cu between each medium diminishes. This may be due to the Cu requirement of *Sorghum* being readily satisfied by efficient Cu uptake, further uptake may then be inhibited. Lockman (1972) reported that *Sorghum* required only 2-7ppm Cu for normal growth.

EDTA-extractable Cu was shown to be higher from perlite than from pumice, this parallels the plant response (see fig 10). However, extractable Cu was not directly related to foliar levels, as the highest levels of extractable Cu were associated with FTE 36 treatments, yet both plants absorbed more Cu from FTE 503 than from FTE 36. This plant response may have been expected as FTE 503 is known to contain a higher

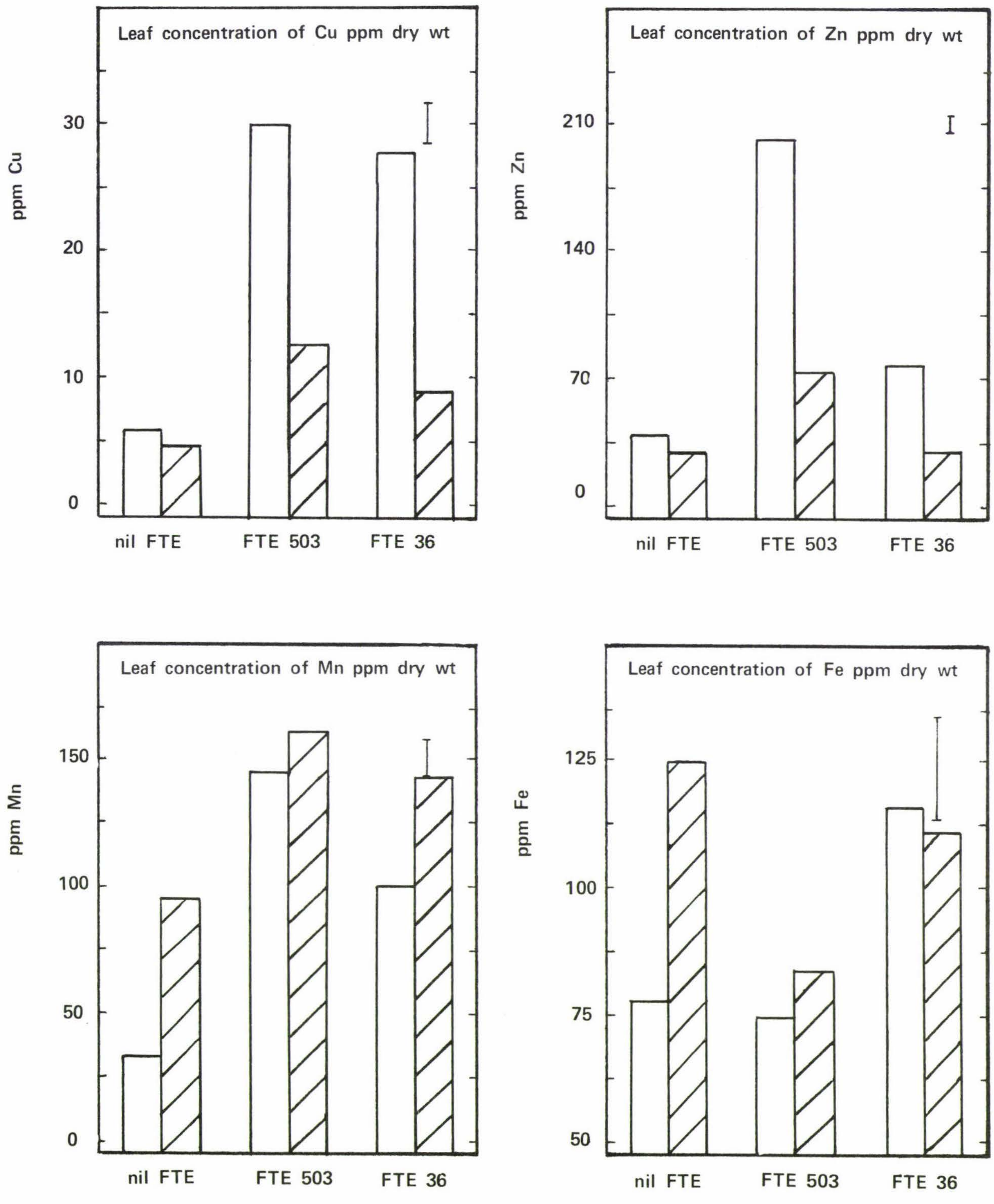

FIGURE 8

Influence of medium and Frit source on the concentration of micronutrients in *Chrysanthemum 'Nob Hill'.*

□ = Perlite ▨ = Pumice I LSD(0.05)

proportion of Cu than FTE 36. The results from EDTA extractions suggest that this reagent is not a good indicator of plant performance or Cu availability from the frits.

The observed difference between the Cu extractable from pumice and perlite could suggest that pumice is adsorbing some of the Cu from the frit which may reduce plant availability. This is in agreement with plant analysis data. Alternatively, the frit may facilitate the release of Cu from perlite by providing ions for isomorphous substitution (Hodgson, 1963).

Without added frit, the foliar Zn levels in Chrysanthemum and Sorghum followed a similar pattern to that noted with Cu levels. Sorghum appeared to absorb significantly more Zn from perlite than from pumice.

Chrysanthemum plants were able to absorb slightly higher levels of Zn from perlite than from pumice, but this increase was not significant.

When either frit was added to each medium the higher levels of foliar Zn occurred where perlite was the medium rather than pumice. The highest Zn level for both test plants was recorded where FTE 503 was used, irrespective of medium. The difference in Zn levels derived from the two frits appears to be a function of their total Zn contents. The relatively higher Zn content of FTE 503, compared with FTE 36, may allow plants to compete more successfully with the medium for Zn from the frit. This may explain the relatively larger effect of FTE 503 on Zn levels, compared with nil FTE or FTE 36 in both media.

EDTA-extractable Zn appears relatable to Zn levels within plants grown in perlite, but not in pumice. Zinc appears to be more readily extractable from perlite, but is held by pumice in a form not readily extracted by EDTA (see fig. 10). Although not EDTA extractable, some of the Zn adsorbed on to pumice is still plant available (see fig. 8, 9).

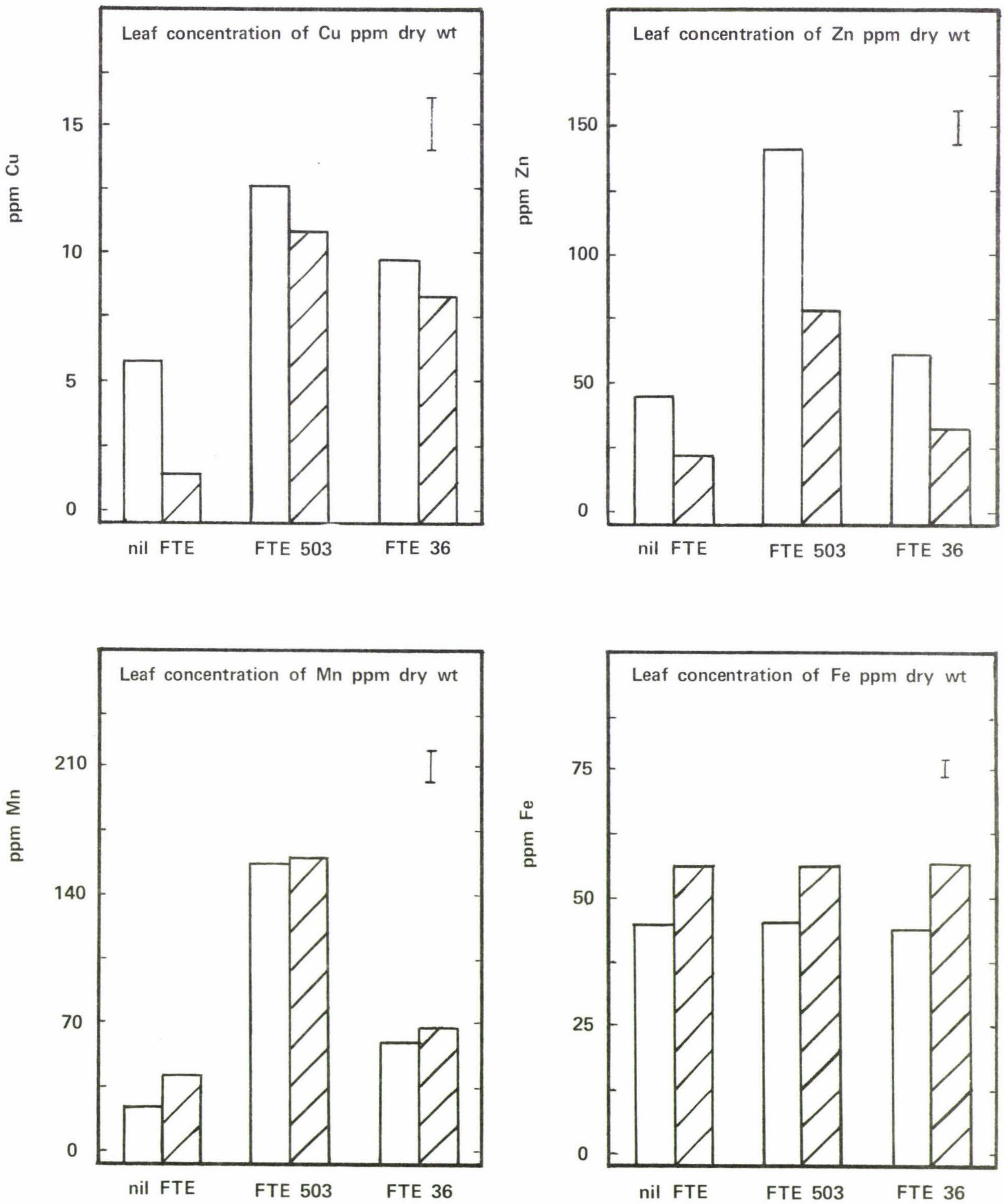

FIGURE 9

Influence of medium and Frit source on the concentration of micronutrients in *Sorghum 'RS610'*.

□ = Perlite ▨ = Pumice I LSD(0.05)

This suggests Zn may be reacting in a manner like Cu, as noted by McLaren and Crawford (1974).

Both Chrysanthemum and Sorghum plants appeared to find the Mn available more readily from pumice than from perlite. The levels of EDTA-extractable Mn follow a similar pattern to that of the test plants.

The addition of FTE to each medium increased foliar Mn in both test plants. The FTE 503 increased the Mn levels to a greater extent than FTE 36. This increase however did not appear directly related to the Mn content of each frit, otherwise a larger response would have been expected from the FTE 503.

As noted above, EDTA-extractable Mn differentiated between perlite and pumice media, but it did not seperate the frit treatments in a manner directly related to plant response. Manganese appeared to be readily extractable from FTE 503, but less extractable from FTE 36. EDTA differentially removed nutrients from FTE 36 as Cu and Zn are readily extractable, but Mn is less so. In contrast, Zn and Mn were more readily extractable from FTE 503 than Cu. Although Mn was not readily extractable plants were able to absorb considerable Mn from FTE 36.

Iron levels in Sorghum plants were significantly higher from in a pumice medium than perlite. Within each medium no significant increase in foliar Fe level attributable to either FTE was observed. This is in agreement with observations by Smilde (1975). The concentrations of Fe detected in Sorghum leaves were on the low side of lockman's (1972) recommendation of 65-100ppm. Nevertheless foliar chlorosis was observed only in the perlite medium (see plate 10).

With Chrysanthemum plants some rather unexpected results were observed. In the absence of FTE, Chrysanthemum plants appeared to be responding in the

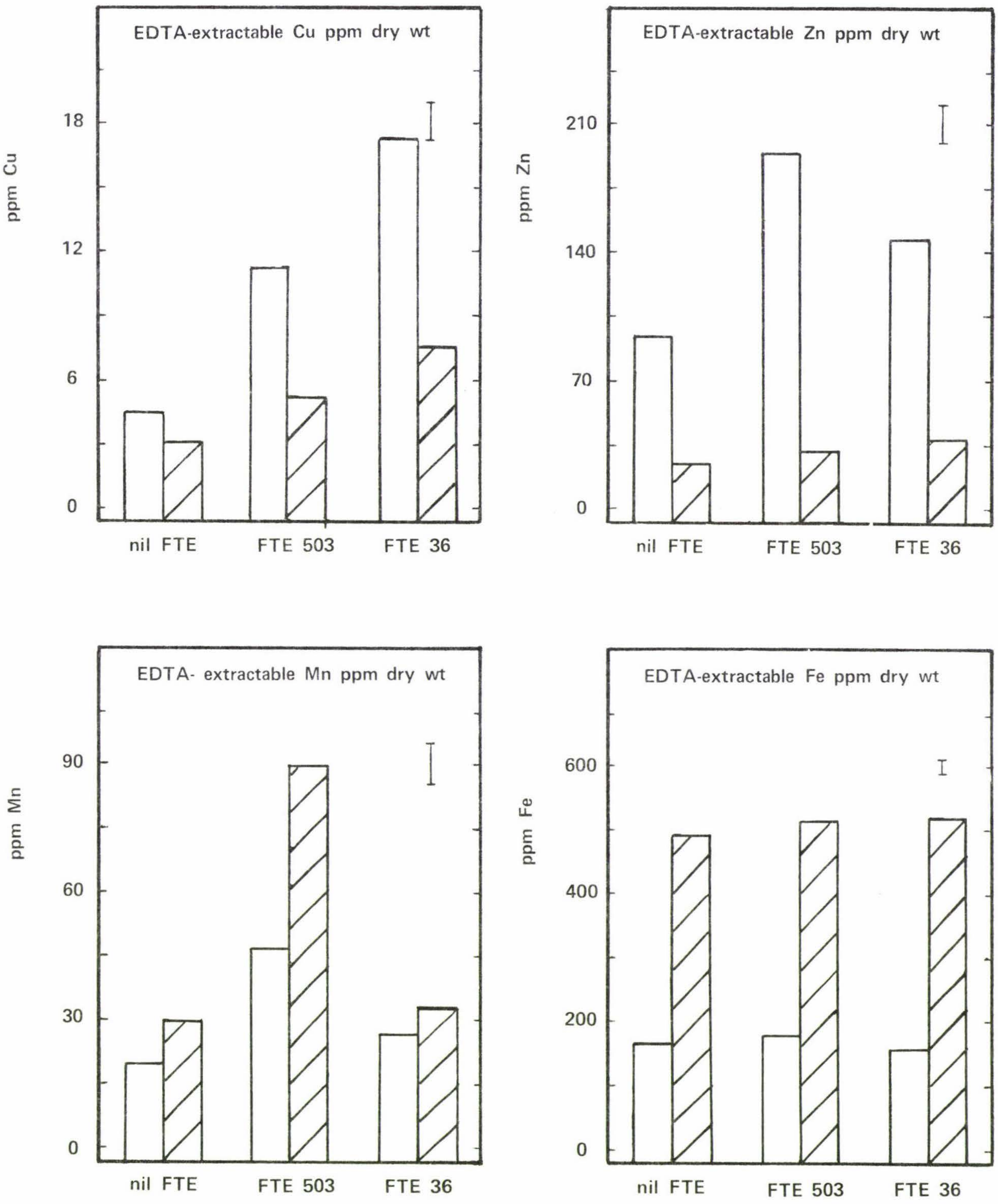

FIGURE 10

Influence of medium and Frit source on EDTA-extractable micronutrients.

☐ = Perlite ▨ = Pumice I LSD(0.05)

same manner as Sorghum plants, except the magnitude of the differences between the media had increased. However with the addition of FTE 503 to each medium, foliar Fe levels were reduced considerably compared with the nil FTE treatment.

This effect may be due to an unresolved interaction between Fe and another ion which inhibits Fe uptake. A similar effect was noted in Experiment I following the addition of FTE 503. When FTE 36 was added to each medium the levels of foliar Fe measured were essentially the same from either perlite or pumice and not significantly different from Fe levels observed in Chrysanthemum plants grown in pumice without FTE. From this information, it would appear that the addition of FTE 36 to a medium effectively reduced the contribution of media component Fe to foliar Fe, this would be an unexpected result. Alternatively, Fe uptake from the perlite medium (with no added FTE) may have been restricted by an undetermined factor. If this were correct, then the addition of FTE 36 to each medium did not increase Fe availability to plants, this conclusion would be in accordance with the work of Wynd and Stromme (1953), Rhoads et al (1956) and Smilde (1975), but conflicting with the observations of Bunt (1971).

The EDTA extracted significantly more Fe from a pumice medium than from perlite. This was not unexpected as the preliminary materials analysis suggested pumice contained higher levels of extractable Fe than perlite. Sorghum plants differentiated between each medium in a manner like the EDTA extractant. As noted previously, Chrysanthemum plants did not follow a similar parallel.

Neither Chrysanthemum or Sorghum differentiated between perlite and pumice with respect to foliar Al. Curiously, relative to the nil FTE treatment the addition of FTE 503 increased foliar Al, yet FTE 36 decreased the Al concentration. Liebig et al (1942) suggested foliage may be a poor indicator of Al toxicity relative to roots. Subsequent analysis of *Sorghum* roots did not show any significant difference in Al level from a perlite or pumice medium, but analysis of *Chrysanthemum* roots did show a significantly higher level of Al apparently coming from the pumice rather than from the perlite.

EDTA-extractable Al was also shown to be higher from pumice than from perlite. These results are similar to thosedescribed in Experiment 3 where *Chrysanthemum* foliage derived more Al from a pumice based medium than from perlite. These results were unexpected as Green (1968), and Gogue and Sanderson (1975) both intimated that perlite released significant amounts of Al. This disparity may reflect a difference in structure and stability of expanded perlite from different sources, as reported by Barnett (1959).

The bicarbonate extractable Phosphate (P) was significantly higher from perlite than from pumice when determined (see table 53). This higher level of media P coincides with the reduced foliar pigmentation of plants grown in pure perlite (see plates 9 & 10).

The relatively higher P availability on perlite may have been attributable to fewer P sorbing sites upon the 'new' expanded perlite compared with the older, more weathered pumice. Alternatively sorbed P may be less strongly immobilised on perlite than on pumice.

Irrespective of the value of these tendered hypotheses, the reactions of phosphate with soilless substrates would be worthy of further investigation.

The application of Fe sprays to chlorotic *Sorghum* foliage resulted in prompt leaf regreening. This response is often regarded as diagnostic evidence of Fe deficiency (Berger and Pratt, 1963). With *Chrysanthemum* plants the immature leaves regreened following the application of

Plate 11 Foliage sections of Sorghum 'RS610' plants grown in perlite with Frit 503 (top) and Frit 36 (bottom), following localised application of Fe SO_4

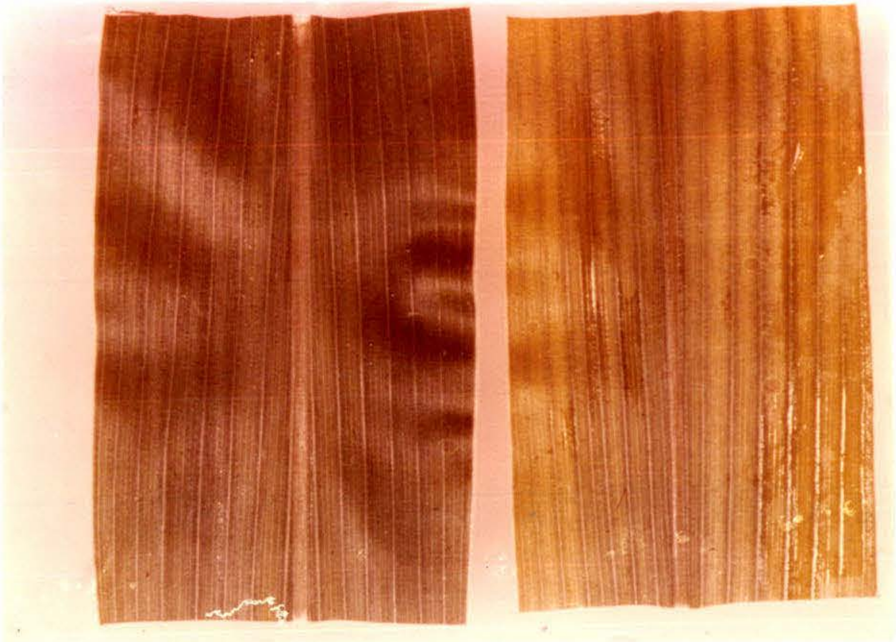

Plate 12 Foliage sections of Sorghum 'RS610' plants grown in New Zealand peat-pumice (left) and New Zealand peat-perlite (right) following application of fluoride to the medium

chelated Fe, but more mature leaves did not regreen as noted by Bunt (1961). The older leaves may have aged physiologically beyond the point where they could respond to an ameliorative Fe spray. Jacobson and Oertli (1956) have suggested that the Fe level in a plant is most critical during the period of chlorophyll synthesis. This supports Richardson's (1969) observation that the normally Fe responsive Sorghum plants may loose their capacity to regreen if they become very Fe deficient. Oertli and Jacobson (1960) have shown that approximately 60ppm Fe is the minimum required for normal chlorophyll synthesis in the leaves of many plant species.

The level of Fe measured in all samples of Chrysanthemum foliage is above this suggested minimum. With Sorghum plants however the foliar Fe level was not above the minimum of 60ppm suggested by Oertli and Jacobson, but was above a threshold value of 40ppm proposed by Lockman (1972) for Sorghum.

As iron is not readily exported from mature leaves (Tiffin, 1972) it may be expected that the estimated foliar Fe levels would be porportional to the Fe levels present in leaves at time of chlorophyll synthesis. Thus chlorophyll synthesis would not appear to be restricted solely by a lack of Fe in the leaves of these particular plants.

Hewitt (1948) considered that where the foliar application of an iron salt restored the green pigmentation, an 'induced iron deficiency' was observed.

Only relatively small differences in Fe levels in test plants appear to have resulted in large differences in foliar pigmentation (see plates 9 & 10). Although iron is present within each plant, the medium appears to effect some control over the amount of Fe actually available for normal metabolic reactions.

The factors promoting Fe chlorosis induction in plants have been reviewed by Wallace and Lunt (1960), but only three out of their fourteen proposed factors appear applicable to this particular experiment:

(a) The potential Fe supply from perlite appears to be rather less than that from pumice, but as previously noted, Fe availability from either medium did not appear to differ greatly, as large differences in foliar Fe levels were not observed, with the exception of the Chrysanthemum plants grown in the nil FTE treatment. The lower pH of the perlite medium (6.2) relative to pumice (6.7) may have increased Fe availability and thus reduced the effect of the difference in Fe in each medium.

If the activity of Fe within the plant was determined by a biochemical method as proposed by Brown and Hendricks (1952), then differences in Fe concentration may have been easier to interpret and relate to the observed chlorosis.

(b) Iron chlorosis may also be induced by excessive levels of heavy metals in the growing medium. Forbes (1917) noted that excessive soil Cu would cause Fe deficiency and stunted root growth in beans and corn, later Chapman et al (1940) showed that an excess of Cu or Zn could produce foliar chlorosis in citrus. Heavy metals may accumulate toxic levels in roots and induce foliar chlorosis without excessively high levels necessarily occurring in foliage (Smith and Specht, 1952). In further studies with citrus Smith and Specht (1953) showed that 'copper appeared to be about 50 times as toxic as Mn and 12 to 15 times as toxic as Zn'. Brown et al (1955) showed that where chlorosis was induced by high levels of Cu the catalase activity or active iron level had decreased significantly.

As previously noted, Cu levels in foliage of plants grown in perlite tended to be higher than normally required for healthy growth (Reuther and Labanauskas, 1966).

Chrysanthemum roots from a perlite medium tended to be shorter, of a larger diameter and with fewer secondary roots than if grown on pumice.

Where Sorghum roots were examined, those grown in perlite were much shorter and with fewer secondary roots which contrasted markedly with the extensive root growth in pumice. Struckmeyer et al (1969) noted that excess Cu caused reduction in root growth and development similar to that observed in plants grown in pure perlite. However, Jackson (1974) in reference to other research workers points out, root growth may be altered by mechanical impedance, nutrient concentration, aeration and waterlogging. Any of these factors, either singly or in combination may have contributed to the observed results and could warrant further investigation.

Smith (1953) noted that an initial absorption of Zn, Mn or Fe by roots would facilitate increased absorption of Cu, thus further increasing metal toxicity. The possibility that Zn could be contributing to chlorosis induction in these experiments cannot be ignored. It has been noted that both foliar Zn and extractable Zn are higher in a medium based on perlite rather than pumice. It is unlikely that Zn levels in foliage have been directly responsible for the observed chlorosis as in the literature higher levels of Zn (than detected in these experiments) have proved non toxic (Smilde, 1975). However, it is conceivable that relatively high Zn levels may interact with Cu to produce a more toxic situation (Smith, 1953).

In New Zealand, nurserymen have successfully prevented the development of Fe chlorosis in perlite based media by the application of chelated Fe. The addition of chelated Fe to a growing medium has often been reported to effectively reduce Cu absorption and its resultant toxicity (Smith 1953; Majumder and Dunn, 1959; Daniels and Struckmeyer, 1973). Similarly, Holmes and Brown (1955) showed that Fe chlorosis may be corrected by adding Fe chelate to the medium with no change in foliar Fe being detected. However, a reduction in foliar Cu and Mn concentrations (which did not approach toxic levels) appeared to correct the observed chlorosis.

In this experiment the plant Mn levels derived from perlite were lower than those from pumice. Perhaps incorrectly, it was considered that Mn levels derived from the perlite medium were not restricting Fe uptake or utilisation as much as Cu or Zn.

(c) High levels of available phosphate may induce Fe chlorosis in plants showing a 'normal' Fe concentration in their tissues, but in chlorotic plants, the ratio P/Fe is increased (De Kock, 1955; Brown et al, 1959). The interaction of Fe and P leading to Fe chlorosis appears to be caused by an internal immobilisation of Fe, probably due to the formation of Fe phosphates (Rediske and Biddulph, 1953). The extractable P levels were significantly higher from a perlite medium (1286 ppm) than from a pumice medium (589 ppm); the higher level of extractable P corresponds with the observed Fe chlorosis. This is in agreement with the observation of Sims and Gableman (1956) where 1000ppm P was required to induce Fe chlorosis in spinach in sand culture. The test plants, Chrysanthemum and Sorghum were selected as test subjects as they both appeared to be susceptible to Fe chlorosis and were possibly Fe-inefficient plants. Brown and Jones (1975) noted that Fe-inefficient Sorghum plants, when Fe stressed, would respond by taking up more P than Fe-efficient plants, thus compounding the problem. Brown et al (1955) have shown that high P produced Fe chlorosis in rice only when accompanied by high Cu availability. This is in accord with the response of plants grown in pure perlite.

However, Spencer (1966) noted an interaction between Cu and P, in which high P reduced Cu toxicity and increased growth at high Cu levels. Conversely, high soil Cu reduced P and Fe concentration in leaves and roots.

Similarly, high levels of Zn may reduce the concentration of both P and Fe in corn foliage (Adriano et al, 1971). Nevertheless, heavy P application to Florida citrus soils is known to have less effect on Cu, Mn and Zn than these micronutrients have on each other (Reuther et al, 1952).

The induction of Fe chlorosis by excess fluoride was not considered by Wallace and Lunt (1960) or Brown (1961) in their reviews. Nevertheless, some circumstantial evidence has suggested fluoride (F) may be a factor worthy of consideration in these experiments.

Hewitt and Nicholas (1963) reported that F may combine with Fe in the heme groups of enzymes, rendering them inactive by the formation of metal-fluoride complexes. Chlorophyll synthesis may also be inhibited by fluorides (Woltz et al, 1971; Wallis et al, 1974). Thus, chlorosis may appear in foliage with apparently normal levels of essential nutrients.

The expression of chlorosis and slight marginal necrosis in Chrysanthemum and foliar chlorosis in Sorghum are symptoms that could have been induced by excess fluoride in the medium (Treshow, 1970). This was verified by growing Sorghum in NZP/Pum or NZP/Per with 200 micrograms F added per pot each week. After 4 weeks plants growing in NZP/Pum showed slight interveinal chlorosis and a pronounced interveinal chlorosis was present in plants grown in NZP/Per (see plate 12).

Poole and Conover (1975) showed that the 17.2 ppm soluble F in their perlite enhanced the development of foliar chlorosis and necrosis. The addition of superphosphate (1.6%F) to the medium also increased plant F and foliar necrosis. Similarly, it may be seen that New Zealand's horticultural perlite contained 43ppm soluble F and the addition of superphosphate increased the soluble F level approximately 7 times. This suggests superphosphate may facilitate the release of fluoride from perlite. Pumice contained 16ppm soluble F, addition of the superphosphate increased the F level approximately 4 times. However this increase is largely attributable to the soluble F in the fertilizer (see table 52).

The effect of superphosphate in a medium may be split into three components, the phosphate or fluoride effects and their interaction. These factors cannot be separated out in this experiment. Nonetheless this may be achieved if a similar experiment were repeated using normal superphosphate and a phosphate compound low in F, such as a high analysis superphosphate (Philips et al 1960) or reagent-grade chemicals to provide phosphate coupled with F applied at known rates.

With peat in the medium, plant F levels (19ppm) appear unchanged by the inorganic media amendment. Hurd-Karrer (1950) noted that plant F was poorly correlated with substrate F, but Poole and Conover (1973) have since shown that plant F could be related to foliar symptoms. The presence or absence of peat in pumice based media did not alter the plant F level (19ppm). However, the plant F derived from a perlite medium without peat was notably higher (33.1ppm). The relatively high fluoride level here corresponds with the most severe Fe chlorosis observed in this experiment. Although suggestive, this does not prove a cause and effect relationship.

The plant samples used for F analysis were not ideal as they were not frozen to prevent loss through F volatilisation (Chapman and Pratt, 1961). The estimates of plant F would therefore be lower than the actual F levels present in living plants. However, similar trends would probably exist in frozen samples.

CHAPTER 4

GENERAL DISCUSSION and SUMMARY

Organic media components

The nutrient content of peat has long been assumed to be of no value to plants (Penningsfeld, 1966; Gallagher, 1972). However in these experiments IP appears to supply more plant available Cu than NZP where pumice is used in the medium. This may have been anticipated as the IP used these experiments had a larger capacity to supply extractable Cu than NZP, and also a smaller capacity to adsorb Cu than NZP. Where perlite is added to the medium this has masked any difference in the peats capacity to supply Cu.

The Zn derived from IP appears more plant available than that from NZP. This is borne out by both the lower Zn sorption capacity and relatively higher levels of extractable Zn in IP compared with that from NZP.

Irish peat and NZP appear to supply similar levels of Mn for plant uptake, but the Mn from NZP appears slightly more plant available. The extractable Mn was higher from IP than from NZP irrespective of the extractant used.

The value of determining EDTA extractable Mn is questionable as it does not appear directly related to plant response in this instance.

Manganese sorption at low Mn levels is similar for each peat, but IP exhibited a larger capacity than NZP to adsorb Mn at relatively higher Mn levels. This accords well with the observed plant response following frit application.

In these experiments IP appeared to supply more Fe for plant uptake than NZP. As with Mn, it is noted that extractable Fe does not mimic plant response. The Fe in NZP is more readily extracted than that from IP.

Foliar Zn levels remained relatively unchanged following peat addition to the medium. Foliar Cu decreased if peat was present in the medium as reported by Pratt et al (1964). Foliar Mn and Fe levels increased with peat in the medium as noted respectively by Cotter and Mishra (1968) and Schnitzer (1969).

In the growing medium peat appears to be functioning in a protective manner, the addition of organic matter to the growing medium has promoted normal root growth and reduced the incidence and severity of foliar chlorosis compared with plants grown without peat.

Hence it appears most probable that the cause of foliar chlorosis is associated with the inorganic media components or the ratio of inorganic to organic components in the medium.

Inorganic media components

Copper appears to be more plant available from perlite than from pumice, particularly after the addition of frit. These results suggest that perlite and pumice have nearly the same capacity to supply Cu for plant uptake in the absence of FTE, but that after FTE addition, Cu is relatively more available from the perlite based substrate. This may arise through pumice having a relatively higher Cu sorption capacity than perlite, as shown previously, and suggested by Esser (1973), or by the frit promoting the release of Cu from perlite.

The Cu levels in plants grown in perlite based media, particularly without a peat amendment, may have been high enough to induce foliar chlorosis (Reuther and Labanauskas, 1966).

Throughout these experiments perlite appears to supply more Zn for plant uptake than pumice. A larger increase in foliar Zn from perlite based substrates than from pumice based media is noted, following the application of frit. This may arise through the perlite actually supplying relatively more Zn than pumice, or pumice adsorbing more Zn, than perlite. The frit may also facilitate the release of Zn from perlite (Hodgson, 1963).

In the absence of peat, the foliar Mn levels in plants suggested that Mn was more available from pumice than from perlite. This is supported by the higher levels of extractable Mn derived from pumice compared with that from perlite. The higher Mn adsorption capacity of pumice did not offset the substrates Mn supplying capacity.

However, with peat present in the medium the plant observed difference between the two inorganic media components tended to diminish. Chrysanthemum was one exception, this test plant showed differences in Mn levels when grown in different inorganic media with or without peat amendment.

The Fe levels in plants grown in pumice based substrates tended to be higher than comparable plants grown in perlite based substrates. This may be anticipated from the large difference between the two media components in extractable Fe. However, the observed differences in foliar Fe levels do not appear to be large enough to explain why Fe chlorosis was seen in perlite based substrates and not in pumice based substrates.

Aluminium levels in plants and media extracts derived from pumice based substrates, were higher than those levels attained in perlite based substrate. Green (1968) noted relatively high Al levels in plants grown in perlite based media; this does not appear to be an important factor controlling plant response in these experiments.

The relatively higher silica content of plants grown in a perlite medium rather than a pumice medium would suggest that those plants predisposed to Si uptake would find this element more available in perlite.

Where media-extractable phosphate has been determined, the results suggest P is relatively more available from a media based on perlite rather than pumice. Although unverified, it is not expected that the peats would alter P availability to the same extent as inorganic media components (Specht, 1952).

Soluble fluorine levels were higher in media made with perlite than pumice, however plant F increased only where perlite was used without peat.

The presence of relatively high levels of P or F, either singly or together may be inducing the Fe chlorosis observed in the test plants (De Kock, 1955; Treshow, 1970). This may occur without reducing the foliar Fe level to a level normally associated with acute iron deficiency.

Media extractant

Without estimating the size of the labile nutrient pool, as proposed by Graham (1973), an extractant may readily remove nutrients that are not plant available. EDTA was used in these experiments to gain some estimate of micronutrient availability. It was considered that a dilute, unbuffered salt would not disrupt the substrate seriously, and would therefore, allow the estimation of a proportion of the nutrients available to the plant.

However, the results suggest that EDTA extracted nutrients could not be related directly to a plant response for all micronutrients.

Fritted trace elements (FTE)

The presence or absence of peat in the medium did not alter the capacity of FTE 36 to increase plant Cu. However, FTE 503 was less effective at increasing plant Cu in a peat based medium. Both frits were less effective at increasing plant Cu in media based upon pumice rather than perlite.

Both FTE 503 and FTE 36 increased plant Zn levels, however, these materials were not particularly effective Zn sources in pumice based substrate. Higher application rates may have allowed plants to compete more successfully with the medium for the fritted Zn or Cu.

FTE 503 increased plant Mn levels more successfully than FTE 36, as noted previously, this may be due to higher frit Mn content. The availability of frit Mn to plants appears genotype dependent.

Neither frit possessed any significant capacity to increase foliar Fe levels, this is supported by the work of Smilde (1975) and many others. The use of FTE 503 consistently reduced foliar Fe levels in *Chrysanthemum* plants.

Nitrogen source

The nitrogen source exerted more influence on the plant nutrient content in a medium based upon perlite rather than pumice. Copper and Zn content of plants tended to be increased with the predominantly NH_4^+ nitrogen source (SCU) instead of the balanced NH_4^+/NO_3^- nitrogen source (OS). This effect occurred irrespective of FTE level.

However plant Mn and Fe levels were increased by the NH_4^+/NO_3^- nitrogen source without added FTE, but with FTE added, the NH_4^+ nitrogen source increased the levels of these elements.

Plant response

The significance of the differential response of plant genotypes to micronutrients may have been underestimated in the past (Brown *et al*, 1972.

In Experiment 3, using a peat based substrate, comparisons between different plant genotypes may be made. It may be seen that all the test plants follow the same trends for Cu, Zn, and Fe uptake from different substrates. However the actual response in a particular medium and nutrient combination is affected by plant interaction with these variables as noted by Bunt (1972). Thus the response is plant genotype dependent. This means, with respect to some micronutrients, a range of plants may be expected to respond in a similar manner in the same medium, but only experimentation will reveal an individual plants response.

Some plants may differ in their response to different micronutrients. With respect to Mn, changes in medium or frit level produced a minimal alteration in foliar Mn of Sorghum. Chinese Cabbage plants responded to the increasing FTE level, but not to any differences in media components. In contrast, Chrysanthemum plants responded strongly to both differences in media and frit levels.

The capacity of the plant to modify the root environment may be an important factor regulating the uptake and translocation of Mn in a manner comparable with that described for Fe by Brown et al (1972).

In Experiment 4, using an inorganic media without peat amendment, both Sorghum and Chrysanthemum plants showed similar capacities for Cu and Zn uptake from FTE 503 and FTE 36. However, without added FTE the plants responded differently. Chrysanthemum plants were more effective at Cu uptake and less effective at Zn uptake from a substrate than Sorghum plants.

Chrysanthemum plants responded more distinctly to differences in Mn medium than Sorghum. Similarly Chrysanthemum found Mn rather more available from FTE 36 than did Sorghum.

In contrast, Sorghum plants responded more distinctly to differences in Fe content of media components than Chrysanthemum plants. The Fe uptake by Chrysanthemum appeared to be inhibited by FTE 503, however this effect was not observed with Sorghum. This may suggest the Fe uptake mechanism of Sorghum is more resistant to inhibition by certain micronutrient combinations than Chrysanthemum.

The analysis of plant foliage has assisted in the identification of nutritional disorders as attested by Jones (1972).

In these particular experiments the absolute results, or nutrient ratios, derived from foliage analysis, have not conclusively indicated the cause of the observed chlorosis in the test plants.

However, differences in the mineral content of plants has shown that plant detectable differences exist between the different types of soilless growth media used.

The sample material chosen for analysis was the same as that used by Lunt et al (1964) and Lockman (1972), as it is well known that the value of the results depends on this material (Bates 1971).

If a nutrient toxicity was suspected in preliminary work then it may have proved more satisfactory to analyse plant roots as they maybe a more reliable indicator of a nutrient excess (Smith and Specht, 1953). Alternatively, monitoring the activity of selected metallo-enzymes could serve as a reliable index for rapid identification of an imminent nutrient deficiency. As the level of active nutrient in the plant is estimated this could be expected to give a more accurate assessment of nutrient status than that given by whole leaf analysis.

Currently research workers have found that the activity of enzymes dependent upon the presence of B, Cu, Fe, Mo or Zn may be correlated closely with plant growth response (Gupta, 1966; Davies and Winsor, 1970; O'Sullivan et al (1969); Randall, 1969; Dwivedi and Randhawa, 1974).

In this work only two organic/inorganic media component ratios have been considered. It is envisaged that, as the proportions of these materials in the medium are altered, the chemical and physical properties of the medium will also alter. If the proportion of peat in the growing medium is reduced below a threshold level, then the protective capacity of the peat will also diminish, below a critical value healthy plant growth may not occur with relatively high nutrient levels in some media.

These experiments, using the vehicle of plant and substrate analysis, have shown that differences in micronutrient availability and extractability exist between the media components used.

Where nurserymen and research workers alike consider the inertness of the medium important, they should investigate the properties of each batch of material. This will enable the true nutrient supply to be more accurately defined and allow a more rational development of nutrient supplies for other media.

APPENDIX

APPENDIX 1.

TABLE NO 46 Mechanical analysis of media components (% composition)

	Size fraction				
Inorganic media components	>2mm	>1mm	>0.5mm	>0.25mm	<0.25mm
Coarse pumice	75.92	22.54	0.64	0.28	0.54
Fine pumice	0.42	16.32	58.94	19.46	4.76
Perlite	30.0	18.6	16.7	17.06	15.86
Organic media components		> 1cm	> 5mm	> 2mm	< 2mm
New Zealand peat		15.59	8.84	25.91	49.67
Irish peat		6.20	19.22	31.18	43.40

TABLE NO 47 Cation exchange capacity of media components

	Exchangeable Acidity	+	Exchangeable Bases	=	CEC
New Zealand peat	46.4		8.75		55.2
Irish peat	25.4		10.9		36.3
Coarse pumice	-		3.3		3.3
Fine pumice	-		3.6		3.6
Perlite	-		1.5		1.5
Vermiculite	-		57.3		57.3 meq/100g

TABLE NO 48 Extractable nutrients

Micrograms of element per gram media component*

Extractant 1N NH_4Ac	Element							
Media component	Zn	Cu	Fe	Mu	K	Ca	Mg	Al
New Zealand peat	4.0	-	2.0	4.8	57	338	170	-
Irish peat	3.3	-	1.0	8.4	36	594	230	-
Coarse pumice	1.5	-	36.4	13.5	78	322	49	168
Fine pumice	1.6	-	38.0	14.4	116	306	81	60
Perlite	6.4	0.48	3.3	3.3	34	42	7	104
Vermiculite	5.6	0.60	34.6	11.8	456	3090	2405	72
Extractant 0.05N EDTA								
New Zealand peat	12.9	0.48	141	5.6	67	362	894	148
Irish peat	16.5	1.6	112	9.0	73	653	1060	108
Coarse pumice	6.1	0.88	29.2	17.8	124	258	58	72
Fine pumice	8.3	1.0	52.8	21.2	189	336	82	68
Perlite	2.8	0.32	8.8	5.1	78	17	56	40
Vermiculite	7.2	0.2	87.6	20.2	413	2405	2300	64
Extractant 0.05N HCl								
New Zealand peat	14.2	1.76	141	6.0	75	504	840	228
Irish peat	17.8	1.84	117	9.0	47	730	908	144
Coarse pumice	7.1	2.0	568	33.2	114	316	59	1260
Fine pumice	12.6	1.96	726	27.4	143	322	81	584
Perlite	6.9	3.0	49.2	9.1	104	39	72	368
Vermiculite	16.7	2.1	486	20.2	458	3198	2520	372

* mean of five determinations

TABLE NO 49 Micronutrient sorption

Percentage adsorbed from original solution*

Media Component	Element								
	Zn		Cu		Mn		Fe		
Concentration(ppm)	10	100	10	100	10	100	10	10+	100+
New Zealand peat	95	34	97	94	97	5.3	96	1	13
Irish peat	75	47	91	90	96	35	94	0	7.6
Coarse pumice	80	26	93	49	79	8	76	-2	30
Fine pumice	86	36	93	60	70	17	53	-2	37
Perlite	59	2.6	86	21	29	1	1.6	2	0

* mean of 3 separate determinations
\+ EDTA salts

TABLE NO 50 2N HCl soluble micronutrients (mg/kg) in fertilizers used

	Cu	Zn	Mn	Fe
Osmocote 18 : 2.6 : 10	-	80	100	660
Osmocote 14 : 6 : 11.6	115	70	140	1150
Agricultural lime	10	33	37	935
Dolomite lime	6	18	175	3200
Superphosphate	25	265	142	5700
FTE 503	3.2%	8.0%	11.6%	8.2%
FTE 36	2.8%	2.8%	2.6%	12.0%

TABLE NO 51 Nutrient supplement (g/l) as used in Experiment 2

Nitrogen source	NH_4^+/NO_3^-		NH_4^+
Osmocote 26 : 0 : 0	3.0	Sulphur coated urea	2.4
Superphosphate	1.5		1.5
Potassium Sulphate	0.3		0.3
Dolomite lime	3.0		3.0

TABLE NO 52 Fluoride levels in media components and plants

Media	Fertilizer *	pH	uF/ml	ppm	Foliar F	ppm
NZP/Pum	+	5.4	28.5	77.9		19.0
	-	5.1	6.7	18.7		
NZP/Per	+	5.3	47.5	200.4		19.0
	-	4.25	6.7	30.0		
Pumice	-	7.1	7.6	15.8	+ Fert	19.0
Perlite	-	7.2	9.5	43.2	+ Fert	33.1
Superphosphate	0.15g/100ml	6.65	28.5			

* Fertilizer rate = 1.5g Super/L
3.0g Dolomite Lime/L

TABLE NO 53 Micrograms of bicarbonate extractable Phosphate per gram of growing medium

(a) Expt. 2

Medium		N source	FTE level (g/m^3)	
Organic	Inorganic		0	200
NZP	per	SCU	552	584
NZP	per	OS	149	182
NZP	pum	SCU	237	194
NZP	pum	OS	169	153

(b) Expt. 3

Medium (unleached)		FTE level
Organic	Inorganic	200g/m^3
NZP	per	2059
NZP	pum	3014

(c) Expt. 4

Medium	FTE level 100g/m^3
Perlite	559
Pumice	1286

APPENDIX II

Experiment I Chrysanthemum

ANOVA TABLES

	Source of Variation	d.f	F ratio	
Foliar Copper	Organic	1	4.43	*
	Inorganic	1	35.75	**
	Frit	1	1.73	
	F.O	1	0.069	
	F.I.	1	0.123	
	O.I	1	30.53	**
	F.O.I	1	0.769	
	Residual	32	Mean Square 3.250	
	Total	39		
Foliar Zinc	Organic	1	7.47	*
	Inorganic	1	588.82	**
	Frit	1	724.92	**
	F.O.	1	255.49	**
	F.I.	1	15.17	**
	O.I	1	0.069	
	F.O.I	1	14.59	**
	Residual	32	Mean Square 71.313	
	Total	39		
Foliar Manganese	Organic	1	35.78	**
	Inorganic	1	200.06	**
	Frit	1	537.64	**
	F.O	1	57.86	**
	F.I	1	3.25	
	O.I	1	0.076	
	F.O.I	1	14.12	**
	Residual	32	Mean Square 107.15	
	Total	39		
Foliar Iron	Organic	1	43.10	**
	Inorganic	1	54.42	**
	Frit	1	42.01	**
	F.O.	1	0.566	
	F.I	1	17.52	**
	O.I	1	0.143	
	F.O.I	1	2.59	
	Residual	32	Mean Square 127.58	
	Total	39		

Experiment 2 Chrysanthemum

ANOVA TABLES

	Source of Variation	d.f.	F ratio	
Foliar Copper	Media	1	609.07	**
	Nitrogen	1	30.09	**
	Frit	1	33.98	**
	M.N.	1	40.12	**
	M.F.	1	22.83	**
	N.F.	1	6.53	*
	M.N.F	1	0.332	
	Residual	32	Mean Square 2.450	
	Total	39		
Foliar Zinc	Media	1	132.21	**
	Nitrogen	1	66.48	**
	Frit	1	4.27	*
	M.N.	1	12.37	**
	M.F.	1	7.79	**
	N.F.	1	4.50	*
	M.N.F	1	0.252	
	Residual	32	Mean Square 128.393	
	Total	39		
Foliar Manganese	Media	1	4.29	
	Nitrogen	1	2.11	
	Frit	1	11.11	**
	M.N.	1	0.510	
	M.F.	1	2.55	
	N.F.	1	24.77	**
	M.N.F.	1	17.17	**
	Residual	32	Mean Square 705.493	
	Total	39		
Foliar Iron	Media	1	10.54	**
	Nitrogen	1	0.016	
	Frit	1	0.676	
	M.N.	1	0.429	
	M.F.	1	1.47	
	N.F.	1	3.97	
	M.N.F	1	0.070	
	Residual	32	Mean Square 128.729	
	Total	39		

Experiment 2 Media

ANOVA TABLES

	Source of Variation	d.f	F. ratio	
Media Copper	Media	1	95.77	**
	Nitrogen	1	1.97	
	Frit	1	774.21	**
	M.N.	1	1.26	
	M.F.	1	98.32	**
	N.F.	1	0.247	
	M.N.F	1	2.29	
	Residual	32	Mean Square 2.142	
	Total	39		
Media Zinc	Media	1	120.32	**
	Nitrogen	1	8.94	**
	Frit	1	61.23	**
	M.N.	1	0.262	
	M.F.	1	25.62	**
	N.F.	1	0.494	
	M.N.F	1	0.977	
	Residual	32	Mean Square 176.250	
	Total	39		
Media Manganese	Media	1	155.51	**
	Nitrogen	1	2.44	
	Frit	1	248.13	**
	M.N.	1	5.54	*
	M.F.	1	16.78	**
	N.F.	1	3.36	
	M.F.N.	1	0.018	
	Residual	32	Mean Square 7.809	
	Total	39		

Experiment 2 Media cont'd

	Source of Variation	d.f	F. ratio	
Media Iron	Media	1	349.25	**
	Nitrogen	1	5.90	*
	Frit	1	8.97	**
	M.N.	1	52.12	**
	M.F.	1	1.18	
	N.F.	1	12.93	**
	M.F.N	1	13.84	**
	Residual	32	Mean Square 320.200	
	Total	39		
Media Aluminium	Media	1	1821.01	**
	Nitrogen	1	6.44	*
	Frit	1	7.73	**
	M.N.	1	0.015	
	M.F.	1	41.05	**
	N.F.	1	12.29	**
	M.F.N.	1	4.22	*
	Residual	32	Mean Square 1.711	
	Total	39		
Media Phosphate	Media	1	520.78	**
	Nitrogen	1	857.67	**
	Frit	1	0.056	
	M.N.	1	494.82	**
	M.F.	1	16.01	**
	N.F.	1	0.815	
	M.N.F	1	0.703	
	Residual	32	Mean Square 610.100	
	Total	39		

Experiment 3a Chrysanthemum

ANOVA TABLES

Element	Source of Variation	d.f.	F ratio	
Foliar Copper	Block	4	0.480	
	Media	1	52.36	**
	T E	4	103.23	**
	M.T E	4	5.94	**
	Residual	36	Mean Square 3.974	
	Total	49		
Foliar Zinc	Block	4	1.70	
	Media	1	1935.27	**
	T E	4	130.01	**
	M.T E	4	74.95	**
	Residual	36	Mean Square 48.866	
	Total	49		
Foliar Manganese	Block	4	2.05	
	Media	1	302.21	**
	T E	4	18.86	**
	M.T E	4	9.02	**
	Residual	36	Mean Square 686.598	
	Total	49		
Foliar Iron	Block	4	1.38	
	Media	1	0.602	
	T E	4	0.212	
	M.T E	4	1.92	
	Residual	36	Mean Square 1881.036	
	Total	49		
Foliar Aluminium	Block	4	0.727	
	Media	1	61.17	**
	T E	4	2.73	
	M.T E	4	3.92	
	Residual	36	Mean Square 72.222	
	Total	49		

Experiment 3 b   Sorghum

ANNOVA TABLES

	Source of Variation	d.f	F ratio	
Foliar Copper	Block	4	0.991	
	Media	1	12.11	**
	T E	4	42.14	**
	M.T E	4	8.06	**
	Residual	36	Mean Square 3.198	
	Total	49		
Foliar Zinc	Block	4	0.244	
	Media	1	73.92	**
	T E	4	39.56	**
	M.T E	4	3.28	*
	Residual	36	Mean Square 177.97	
	Total	49		
Foliar Manganese	Block	4	2.08	
	Media	1	0.0017	
	T E	4	10.09	**
	M.T E	4	4.97	**
	Residual	36	Mean Square 405.12	
	Total	49		
Foliar Iron	Block	4	3.26	*
	Media	1	2.61	
	T E	4	2.60	
	M.T E	4	3.90	**
	Residual	36	Mean Square 174.59	
	Total	49		

Experiment 3 c Chinese Cabbage

ANOVA TABLES

Foliar Copper	Source of Variation	d.f	F ratio	
	Block	4	4.08	**
	Media	1	148.52	**
	T E	4	109.13	**
	M.T E	4	10.71	**
	Residual	36	Mean Square 2.258	
	Total	49		
Foliar Zinc	Block	4	1.01	
	Media	1	57.78	**
	T E	4	52.97	**
	M.T E	4	1.95	
	Residual	36	Mean Square 254.813	
	Total	49		
Foliar Manganese	Block	4	3.35	
	Media	1	2.94	
	T E	4	22.88	**
	M.T E	4	1.97	
	Residual	36	Mean Square 592.583	
	Total	49		
Foliar Iron	Block	4	2.16	
	Media	1	4.91	
	T E	4	1.01	
	M.T E	4	1.54	
	Residual	36	Mean Square 236.50	
	Total	49		

Experiment 3 Media

ANOVA TABLES

	Source of Variation	d.f	F ratio	
Media Copper	Block	4	0.829	
	Media	1	1.27	
	T E	4	137.01	**
	M.T E	4	0.496	
	Residual	36	Mean Square 9.790	
	Total	49		
Media Zinc	Block	4	1.44	
	Media	1	560.54	**
	T E	4	123.80	**
	M.T E	4	19.18	**
	Residual	36	Mean Square 19.963	
	Total	49		
Media Manganese	Block	4	0.892	
	Media	1	51.82	**
	T E	4	49.03	**
	M.T E	4	0.954	
	Residual	36	Mean Square 34.392	
	Total	49		
Media Iron	Block	4	0.54	
	Media	1	700.67	**
	T E	4	1.13	
	M.T E	4	0.494	
	Residual	36	Mean Square 1224.622	
	Total	49		
Media Phosphate	Media	1	19.26	**
	Residual	8	Mean Square 118,308.9	
	Total	9		

Experiment 4 a Chrysanthemum

ANOVA TABLES

	Source of Variation	d.f	F ratio	
Foliar Copper	Block	4	0.735	
	Media	1	277.42	**
	T E	2	174.29	**
	M.T E	2	52.99	**
	Residual	20	Mean Square 4.224	
	Total	29		
Foliar Zinc	Block	4	1.52	
	Media	1	360.30	**
	T E	2	385.90	**
	M.T E	2	120.44	**
	Residual	20	Mean Square 77.456	
	Total	29		
Foliar Manganese	Block	4	2.07	
	Media	1	8.91	**
	T E	2	141.33	**
	M.T E	2	48.36	**
	Residual	20	Mean Square 140.786	
	Total	29		
Foliar Iron	Block	4	1.31	
	Media	1	7.26	*
	T E	2	11.19	**
	M.T E	2	6.29	**
	Residual	20	Mean Square 286.800	
	Total	29		
Foliar Aluminium	Block	4	1.01	
	Media	1	0.233	
	T E	2	8.39	**
	M.T E	2	0.517	
	Residual	20	Mean Square 175.583	
	Total	29		

Experiment 4 b Sorghum

ANOVA TABLES

	Source of Variation	d.f	F ratio	
Foliar Copper	Block	4	0.572	
	Media	1	19.91	**
	T E	2	72.07	**
	M.T E	2	2.94	
	Residual	20	Mean Square 2.354	
	Total	29		
Foliar Zinc	Block	4	1.01	
	Media	1	126.12	**
	T E	2	194.89	**
	M.T E	2	13.13	**
	Residual	20	Mean Scuare 86.476	
	Total	29		
Foliar Manganese	Block	4	1.75	
	Media	1	3.13	
	T E	2	188.21	**
	M.T E	2	0.543	
	Residual	20	Mean Square 226.330	
	Total	29		
Foliar Iron	Block	4	3.35	*
	Media	1	105.74	**
	T E	2	0.091	
	M.T E	2	0.353	
	Residual	20	Mean Square 10.213	
	Total	29		
Foliar Aluminium	Block	4	1.02	
	Media	1	0.031	
	T E	2	5.25	*
	M.T E	2	0.842	
	Residual	20	Mean Square 107.917	
	Total	29		

Experiment 4 Media

ANOVA

	Source of Variation	d.f	F ratio	
Media Copper	Block	4	0.840	
	Media	1	142.87	**
	T E	2	112.32	**
	M.T E	2	25.43	**
	Residual	20	Mean Square 1.627	
	Total	29		
Media Zinc	Block	4	0.745	
	Media	1	320.12	**
	T E	2	24.23	**
	M.T E	2	18.32	**
	Residual	20	Mean Square 299.860	
	Total	29		
Media Manganese	Block	4	1.32	
	Media	1	64.81	**
	T E	2	145.40	**
	M.T E	2	20.63	**
	Residual	20	Mean Square 42.070	
	Total	29		
Media Iron	Block	4	1.80	
	Media	1	3375.65	**
	T E	2	4.32	*
	M.T E	2	2.95	
	Residual	20	Mean Square 253.826	
	Total	29		
Media Aluminium	Block	4	1.33	
	Media	1	243.70	**
	T E	2	3.62	**
	M.T E	2	2.24	
	Residual	20	Mean Square 541.667	
	Total	29		
Media Phosphate	Media	1	9.44	*
	Residual	8	Mean Squares 140023.0	
	Total	9		

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