EFFECT OF CONTROLLED-RELEASE FERTILIZERS ON NUTRIENT COMPOSITION AND ROOTING PHYSIOLOGY OF CUTTINGS

by

Juan E. González

A thesis submitted to the Faculty of Graduate Studies and Research of McGill University in partial fulfilment of the requirements for the degree of Master of Sciences

Department of Plant Sciences,
Macdonald College of
McGill University,
Montreal.

ABSTRACT

EFFECT OF CONTROLLED-RELEASE FERTILIZERS ON NUTRIENT COMPOSITION AND ROOTING PHYSIOLOGY OF CUTTINGS

HORTICULTURE JUAN E. GONZALEZ M.Sc.

Stem cuttings of Euonymus alata, Philadelphus coronarius 'Aureus', Weigela 'Bristol Ruby', Cotoneaster acutifolia and Juniperus sabina were rooted under intermittent mist in medium 1:1 (v/v) perlite and peat moss amended with different formulations and rates of incorporated or surface-applied Osmocote controlled-release fertilizer.

Rooting performance (rooting percentage, root length and root number) generally was adversely influenced by increasing rates of Osmocote (0 to 0.6 kg/m^2 surface-applied and 0 to 4.0 kg/m^3 incorporated). Leaching losses of N, P and K from cuttings were generally higher than apparent uptake of these nutrients from the medium by the cuttings. Consistent negative correlations between K content and rooting performance were observed in all species studied. An inverse relationship between rooting performance and levels of soluble salts in the rooting medium was observed for all species. Juniperus and Cotoneaster cuttings appeared to be more tolerant to soluble salts than Euonymus, Philadelphus and Weigela. A suggested model relating critical levels of soluble salts with slopes of the regression curves between rooting performance of the various species studied and soluble salts in the rooting medium was advanced.

RESUME

EFFETS DES ENGRAIS A RELACHEMENT CONTROLE SUR LA COMPOSITION NUTRITIVE ET LA PHYSIOLOGIE D'ENRACINEMENT DES BOUTURES

HORTICULTURE JUAN E. GONZALEZ M.Sc.

Les boutures de tige de Euonymus alata, Philadelphus coronarius 'Aureus', Weigela 'Bristol Ruby', Cotoneaster acutifolia et Juniperus sabina ont été enracinées sous un système de nébulisation sous brouillard, dans un substrat d'enracinement 1:1 (v/v) de perlite:mousse de tourbe, amendé avec différentes formulations et taux d'Osmocote, incorporé au substrat ou appliqué en surface.

La performance d'enracinement (pourcentage d'enracinement, longueur des racines et nombre de racines) a été défavorablement influencée par une augmentation du taux d'Osmocote (0 à 0.6 kg/m^2 appliqué en surface et 0 à 4.0 kg/m^3 incorporé). Les pertes par délavage de N, P et K provenant des boutures étaient généralement plus grandes que l'apport apparent en éléments nutritifs du substrat d'enracinement aux boutures. Des corrélations négatives constantes entre le contenu en K et la performance d'enracinement ont été observées pour toutes les espèces étudiées. Une relation inverse entre la performance d'enracinement et le niveau de sels solubles dans le substrat d'enracinement a été notée pour toutes les espèces. Les boutures de Juniperus et de Cotoneaster semblent être plus tolérantes aux sels solubles que celles de Euonymus, Philadelphus et Weigela. Un model statistique a été suggéré concernant les niveaux critiques de sels solubles avec les pentes des courbes de régression entre la performance d'enracinement des différentes espèces étudiées et les sels solubles du substrat d'enracinement.

ROOTING WITH CONTROLLED-RELEASE FERTILIZER

(suggested short title)

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. C. Chong, director of this study, for his continued enthusiasm, advice, criticisms and patience during all stages of this work.

Special thanks is directed to C. Richer-Leclerc for her continued suggestions and assistance throughout all phases of this study.

Appreciation is extended to Dr. W. E. Sackston for his support and comprehension. Thanks also to Dr. N. Arnold for his advice and assistance during chemical analyses of this study.

The continued encouragement and assistance from my wife are deeply appreciated.

The support of this project by the Conseil des recherches et services agricoles du Québec (C.R.S.A.Q.) is acknowledged.

August 1982

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

1. INTRODUCTION

Propagation by stem cuttings is an important method of propagating ornamental shrubs (Hartmann and Kester 1975). It is based on the capability of cells to return to the meristematic condition and regenerate new plants with the same genotype of the mother plant (Tukey 1979).

The discovery and use of auxins in stimulating adventitious root formation in cuttings marked the beginning of major advances in cutting propagation techniques (Cooper 1935; Wareing 1973). The later application of intermittent mist (Loach 1979) made possible the rooting of cuttings from plants previously considered almost impossible to root (Snyder 1954). These techniques, now commonly used by nurserymen all over the world, increase rooting percentage, insure uniformity and speed of rooting, enhance the quality of the root system, and improve viability after transplanting (Hartmann and Kester 1975; Whitcomb et al. 1978).

The leaching of metabolites, including mineral nutrients, from cuttings under intermittent mist is a disadvantage of this technique (Good and Tukey 1964, 1965, 1966; Sharpe 1955). Thus, the practice of keeping cuttings under mist as long as possible to obtain higher rooting percentages and better uniformity,

increases the need for nutrients to the cuttings (Gouin 1974).

Nutrient mist, the technique of adding soluble fertilizers to the water used in the mist system (Wott and Tukey 1965), has proved to be effective in replenishing the nutrient loss (Sorensen and Coorts 1968; Wott and Tukey 1967). However, nutrient mist does not always improve rooting (Keever and Tukey 1979; Sorensen and Coorts 1966, 1968; Wott and Tukey 1965, 1967) because secondary problems, such as growth of algae on the medium resulting in reduction in aeration and drainage, have restricted its use as a practical propagating technique (Coorts and Sorensen 1968; Gouin 1974; Wott and Tukey 1967).

Controlled-release fertilizers appears to be a feasible alternative way of supplying small amounts of nutrients to the rooting medium (Chong 1982b; Whitcomb et al. 1978). This practice seemed to have effect on rooting ability (Deen 1973; Dinter and Eaton 1976; Johnson and Hamilton 1977; McGuire and Bunce 1970) and on vigour of the rooted cuttings (Carney and Whitcomb 1981; Richards and Whitcomb 1980; Ward and Whitcomb 1979).

The purpose of this study was to investigate the effects of controlled-release fertilizers in the rooting medium on the nutrient composition and rooting physiology of stem cuttings of selected woody ornamental shrubs during propagation. These

studies evaluated the ability to root, the tolerance of cuttings to soluble salts levels and pH of the medium, and the capability of the potential nutrient uptake to counteract the leaching effect due to mist.

2. REVIEW OF LITERATURE

2.1 Physiology of Rooting

It has long been recognized that the vegetative propagation of plants from cuttings resulted in more uniform planting stocks in a shorter period of time than those grown from seeds (Zimmerman 1925).

2.1.1 Role of Growth Regulators and Rooting Substances

Tukey (1979) considered the rooting process, both initiation and development, as a combination of many processes in which certain cells can be activated to form roots. According to Hartmann and Kester (1975), certain natural internal factors are necessary for the formation of root initials and subsequent root development. For instance, ample evidence has indicated that rooting is regulated by plant hormones (Hartmann and Kester 1975; Snyder 1974; Wareing 1973). In the 1930's, indoleacetic acid, first identified as a natural growth regulator with auxinic activity (Thimann 1935), was used successfully to promote rooting of stem cuttings (Cooper 1935). Tukey (1979) stated that indoleacetic acid was synthesized mainly in developing buds, young leaves, root tips, pollen and fruits. Presently, related synthetic auxins, notably indolebutyric acid (IBA) and naphthaleneacetic acid, are commonly

used in cutting propagation (Doran 1957) because they are more stable and more mobile than naturally-produced auxins (Tukey 1979; Wareing 1973).

Haissig (1972) indicated that the endogenous accumulation of natural auxins at the base of cuttings, resulting from basipetal translocation from buds and leaves, or from exogenous application of auxins, was the primary rooting stimulus. Wareing (1973) suggested that endogenous auxin levels were usually adequate to induce rooting in cuttings of herbaceous species that rooted easily. Although softwood cuttings of many woody plants responded similarly (Doran 1957), Smith and Wareing (1972) suggested that the general decrease in rooting ability of woody plants with seasonal progression was probably due to a depletion of auxins in buds and young leaves as these plants approached dormancy in the fall.

Other evidence indicated that substances other than auxins also played a fundamental role in the rooting process (Snyder 1974; Tukey 1979). The term "rhizocaline" has been used since the 1930's to refer to unidentified endogenous substances which promoted rooting (Hartmann and Kester 1975). Hess (1965b) demonstrated the existence of a group of rooting cofactors, which were required for rooting of certain species. These cofactors, produced in the leaves, helped to explain differ-

ences in rooting ability of many species and cultivars (Snyder 1974).

The balance of auxins and rooting cofactors did not always correlate with rooting, suggesting that the role of other growth regulators or substances, such as an enzyme or a group of enzymes, interacted with the complex auxin-cofactors to initiate the rooting process (Bouillene and Bouillene-Walrand 1955). Tukey (1979) stated that although no one universal enzyme has been isolated and purified, evidence supported the action of a complexing enzyme, probably of the polyphenol oxidase type, in the rooting process.

Although the presence of auxins have been shown to be essential in the rooting process (Doran 1957; Wareing 1973), exogenous applications of auxins have shown little or no influence on the rooting of many difficult-to-root species (Doak 1940; Hess 1962). However, Chong (1981, 1982a) and other researchers (Brown and Dirr 1976; Still 1981) reported favorable rooting response of certain difficult-to-root species to high IBA concentrations between 10,000 and 40,000 ppm. These species included Cotoneaster acutifolia, Malus 'Hopa' and Taxus cuspidata (Chong 1981, 1982a).

Gorter (1969) described certain metabolic products, es-

pecially of the phenolic type, acting synergistically with auxins on rooting. Bachelard and Stowe (1962) correlated anthocyanin pigmentation with rooting. These substances seemed to inhibit the activity of the indoleacetic acid oxidizing system (Basu and Ghosh 1974; Lee and Tukey 1971a, 1971b). Spiegel (1954) demonstrated the existence of natural inhibitors on root initiation in Vitis vinifera. Furthermore, Fadl and Hartmann (1967) found a correlation between rooting inhibitor concentration and difficulty in rooting of different pear cultivars.

Since the 1950's, other groups of natural plant hormones have been recognized (Hartmann and Kester 1975). These plant hormones, which are all chemically different from each other (Wareing 1973), included the growth promoters, cytokinins and gibberellins; the growth inhibitor, abscisic acid; and ethylene, the only plant hormone which is in the gaseous form (Wareing 1973).

Exogenous applications of cytokinins generally have not been effective in promoting rooting (Skoog and Tsui 1948). Gibberellins applied at high concentrations of 10^{-3} M have reduced rooting in many instances (Hartmann and Kester 1975). Ericksen (1974) found a gibberellin-promotive effect on rooting of pea cuttings when applied at low concentrations of 10^{-11}

to 10^{-7} M. Wareing (1973) indicated that abscisic acid promoted rooting in some species such as Hedera helix, probably by supressing the effect of naturally existing gibberellins. Treatments with ethylene have yielded contradictory results on rooting of cuttings (Chong 1982c; Swanson 1974) suggesting an indirect effect (Hartmann and Kester 1975).

2.1.2 Role of Mineral Nutrients

The mineral nutrient status of cuttings has considerable influence on root formation and development (Kamp and Bluhm 1950). Biron and Halevy (1973) indicated that removing the growing point of Dahlia cuttings increased rooting because of lower competition for nutrients of the growing point with the rooting region of the stem.

The stimulative effect of P on root growth has been extensively demonstrated (Kramer 1969), although Graca and Hamilton (1981a) observed that root growth of Cotoneaster divaricata was not improved with P applications. Swanson and Davis (1977) found that P-deficient cuttings of Plectranthus australis showed shorter roots and lower rooting percentage. Furthermore, they observed that in the few cuttings that rooted, roots were weak and possesed black root hairs.

Ca deficiency characteristically has been found to supress

root growth (Kramer 1969). This effect was probably associated with the role of Ca in the middle lamella of the cell wall (Swanson and Davis 1977).

Gorter (1958) considered B as the most important inorganic compound involved in the rooting process. Albert (1975) stated that root elongation ceased in the absence of B. Because root growth was ultimately dependent on cell division of meristems, B seemed to prevent cell division and DNA synthesis (Albert 1975). It has been suggested that auxins stimulated the formation of root initials (Tukey 1979; Wareing 1973) and that B was necessary for elongation and development of those initials (Albert 1975; Gorter 1958). However, Weiser and Blaney (1960) found a synergistic B-IBA interaction resulting in increased rooting percentage, root number, and to a lesser extent root length. The rooting process of cuttings of difficult-to-root Ilex aquifolium was also hastened, suggesting an effect of B on root initiation as well as on root growth (Weiser and Blaney 1960).

Starring (1923) reported beneficial effects of N-deficiency on rooting of cuttings, but he concluded that the decisive factor was the ultimate level of carbohydrates in the cuttings as influenced by N. Root growth was not increased by N indicating that rooting varied inversely with N status (Graca and Hamilton

1981a). Good and Tukey (1967) found that N was required during root elongation of chrysanthemum cuttings, but not during root initiation. Carney and Whitcomb (1980) stated that N was very important in the early growth of liners (small nursery plantlets) following transplanting. Greater root length and healthier root appearance was found in cuttings under N-deficient regime (Swanson and Davis 1977).

Although K is considered an important factor in the activation of enzymes, its deficiency did not affect root initiation and development (Swanson and Davis 1977). Sorensen and Coorts (1968) observed a negative correlation between K content and rooting percentage of cuttings of several species. Swanson and Davis (1977) found no influence of Mg and S content on rooting, while Bindra (1976) reported favorable effects of Fe on rooting of peach almond hybrids.

2.1.2.1 Mineral Translocation

Inorganic elements have shown large differences in mobility within the plant. Bukovac and Wittwer (1957) estimated that Ba, Ca, Mg and Sr were not translocated from leaves to the new growth. On the other hand, Van Goor and Wiersma (1974) considered Ca to be highly immobile, while K was very mobile; they found that Mg and Mn mobility depended on their concentrations in the leaf.

In studies with chrysanthemum cuttings, Good and Tukey (1965, 1967) showed that N was translocated acropetally (i.e. from older tissues to apex or newer leaves), but little if any N was translocated basipetally to new roots during root initiation or during early root development. They also found an increase in basipetal N translocation only when root growth was at a maximum, suggesting that the requirements for N during root initiation and early development could be satisfied by the N present at the cutting bases. Furthermore, Good and Tukey (1965, 1967) showed that P was translocated basipetally from the older leaves towards both the new leaves and new roots more or less steadily throughout the rooting period, indicating that P was associated with both root initiation and development, and that this requirement was met by translocation from older tissues. In chrysanthemum cuttings, K was continuously translocated from the oldest leaves to the new leaves, but virtually none to new roots (Good and Tukey 1965, 1967).

Blazich and Wright (1979) found constant nutrient content in leaves, upper stems and lower stems of Ilex crenata cuttings indicating no basipetal translocation of N, P, K, Ca and Mg during the root initiation period. Wott and Tukey (1969) observed that P translocation to the basal portions of a cutting was considerable before root initiation, followed by a decrease when root initials were first observed, and another increase

when roots were elongating.

In another experiment, Good and Tukey (1967) showed that about 10% of labelled P in cuttings was translocated from older tissues to growing leaves, and little to new roots.

2.1.2.2 Mineral Nutrition of Stock Plant

Any technique of growing stock plants that can result in obtaining rooted cuttings more quickly and in a greater number is of interest (Preston et al. 1953).

The physiological condition of stock plants has been known to affect markedly the rooting of cuttings (Haun and Cornell 1951; Pearse 1943). Vigorous parent plants seemed to produce healthier cuttings with more rooting (Sharpe 1955; Ward and Whitcomb 1977). Greater cutting production was obtained from stock plants subjected to high N levels (Eck and Stretch 1979; Preston et al. 1953), but such stock plants produced soft cuttings susceptible to rotting (Kamp and Bluhm 1950; Starring 1923).

It has been extensively demonstrated (Basu and Ghosh 1974; Haun and Cornell 1951; Pearse 1943) that stock plants receiving low N levels yielded cuttings that rooted more readily than cuttings taken from plants grown under high N levels. Preston

et al. (1953) obtained similar results when using softwood cuttings in early spring. With more mature cuttings, he obtained a higher degree of rooting and better survival in those taken from stock plants receiving high levels of N. Pearse (1943) and Basu and Ghosh (1974) found better response to auxin treatment of cuttings from N-starved plants.

Basu and Ghosh (1974) demonstrated that rooting cofactor activity, anthocyanin pigmentation and root number of cuttings were inversely related to N supply to stock plants, although the highest dry weight per root was obtained with the highest level of N. These results were in agreement with those of Haun and Cornell (1951). Eck and Stretch (1979) working with blueberry demonstrated no influence of N on rooting percentage and quality of cuttings taken from those stock plants.

P and K levels in stock plants did not seem to influence rooting response of cuttings (Haun and Cornell 1951; Preston et al. 1953). According to Coorts (1969), rooting percentage decreased in cuttings taken from micronutrient-deficient plants. Although rooting was less numerous, he found better quality roots in cuttings from plants deficient in either Zn or B. Starring (1923) and Pearse (1943) recommended special nutritional treatments to plants cultivated exclusively for cutting production.

2.2 The Rooting Environment

According to Snyder (1974), rooting response of cuttings could be supressed by unfavorable rooting environment. Temperature of the air and of the rooting medium, moisture status of cuttings, light quality and quantity, and aeration of the rooting medium are the principal external environmental factors influencing rooting (Snyder 1974).

2.2.1 Role of Misting

Zimmerman (1925) recognized that the presence of foliage, in addition to supplying auxins and related rooting cofactors, speeded the rooting process by maintaining cuttings in a turgid condition during rooting. According to Loach (1979), transpiration was the main source of water loss from cuttings. He related transpiration directly to the water vapor pressure gradient between the inside of the leaf and the surrounding air. Misting, which covered the leaf surfaces of cuttings with a thin film of water (Snyder 1954) reduced water loss from cuttings by diminishing the vapor pressure gradient (Tukey 1978). The misting technique enabled a greater number of species to be propagated by softwood cuttings during the growing season (Tukey 1975) and was especially advantageous for rooting difficult-to-root species (Snyder 1954). During winter under greenhouse condition, misting of evergreens reduced the time

cuttings were in the propagation bench (Nelson 1959), and also incidence of diseases and insects (Snyder 1965).

According to Loach (1979), misting was used for the first time by Spencer in 1936, although the first written reports of the propagation of softwood cuttings of several species under mist was presented by Raines, Gardner and Fisher in 1940 and 1941. Fisher (1943) reported successful rooting of conifer cuttings under mist.

Commercial acceptance of the misting technique occurred during the 1950's (Loach 1979). Templeton (1953) described a control device for intermittent mist in which cuttings were misted for brief intervals during the day when transpiration was greatest. In its early use, intermittent mist was controlled by time clocks, but recently more accurate devices, such as leaf sensor and solar controls, have been introduced (Loach 1979).

In mist propagating benches, Hess and Snyder (1955) demonstrated lower leaf temperatures in misted as compared to unmisted cuttings because of evaporation (Tukey 1978) and also lower air temperature in the misting environment (Loach 1979). Hess (1965a) indicated that the rate of respiration was generally doubled for every 5°C increase in temperature.

According to Hess (1965a) and Tukey (1978), cuttings under mist can be subjected to higher light intensities without increasing leaf temperature, thereby enabling higher net accumulation of photosynthates which can be more effectively utilized for root development.

Lee and Tukey (1971a, 1971b) found increased levels of auxin-like substances as well as rooting cofactors in misted plants of Euonymus alatus 'Compactus' as compared with unmisted plants.

2.2.1.1 Leaching of Cuttings

The term leaching, originating from the loss of mineral ions in soils, was first applied to plants by Mann and Wallace (1925) to describe the loss of nutrient elements from leaves soaked in water. A major effect of mist was the leaching of metabolites from cuttings (Good and Tukey 1966; Snyder 1965; Tukey 1975).

Morgan and Tukey (1964) found that a diversity of metabolically important substances were leached from leaf tissues. These substances included inorganic macro- and micro-nutrients, amino acids, organic acids, alkaloids, vitamins, free sugars and other carbohydrates, phenolic substances, and plant growth inhibitors and regulators. Lee and Tukey (1971a, 1971b) showed

that misting resulted in extended seasonal growth of Euonymus alatus 'Compactus', probably due to leaching of inhibitors involved in senescence and dormancy.

Even before leaching was definitely demonstrated, deficiency symptoms developed in cuttings under mist for prolonged periods of time (Gouin 1974) suggested the occurrence of leaching of nutrients either by actual loss and/or by dilution of the existing nutrients (Good and Tukey 1964). Evans (1951) reported heavy losses of N, P and K from cacao cuttings under continuous mist. Sharpe (1955) found markedly lower percentages of N, P and K in leaves of many species after 30 days under mist. Lee and Tukey (1971a, 1971b) showed lower concentrations of total N in leaf tissues of plants subjected to mist due to leaching.

Sharpe (1955) and Wott and Tukey (1965) demonstrated that K was more easily leached from cuttings than were N, P, Ca and Mg. Tukey et al. (1958) considered Na and Mn to be easily leached; Ca, Mg and K to be moderately leached; and Fe, Zn, P and Cl to be more difficult-to-leach.

Mecklenburg et al. (1966) stated that environmental factors generally had little effect on leaching. K salts in the misting solution leached more than distilled water, while Na

salts leached similarly to distilled water and Ca salts decreased leaching (Tukey 1970). Bhan et al. (1959) observed that easily-wetted leaves normally had more leaching.

Tukey and Morgan (1964) showed that the physiological status of cuttings had a marked influence on leaching. For instance, cuttings from healthy and vigorous plants showed less leaching (Tukey and Morgan 1964). Young growing tissues, i.e. herbaceous and softwood cuttings, did not leach appreciable quantities of mineral nutrients, whereas more mature tissues, i.e. hardwood cuttings, were more susceptible to leaching under mist (Good and Tukey 1964, 1967; Mecklenburg and Tukey 1964). Good and Tukey (1965) found that susceptibility to leaching of both organic and inorganic substances was inversely related to the growth cuttings made during the rooting period.

Mecklenburg and Tukey (1964) observed that the energy level of tissues had little effect on leaching, supporting the idea of leaching as a passive process. Mecklenburg et al. (1966) postulated that cations were exchanged by H from the leaching solution or were diffused directly from the translocation stream to the leaching solution. The H of the leaching solution originated from the carbonic acid resulting from carbon dioxide dissolved in water on leaf surfaces (Tukey 1970). This hypothesis helped to explain why alkaline carbonates were the princi-

pal components of leachates (Morgan 1963).

According to Morgan and Tukey (1964), leaching did not simply eliminate metabolic waste products. The organic and inorganic substances leached from upper leaves of cuttings and absorbed by the roots were intercepted and reabsorbed directly by leaves below and/or those fallen into the rooting medium (Tukey and Mecklenburg 1964). Tukey et al. (1958) stated that nutrients lost by leaching were replenished by root uptake and translocation from other plant parts. Mecklenburg and Tukey (1964) demonstrated that the rate of translocation of Ca from roots to upper parts was higher in plants subjected to leaching than in unleached plants, independently of growth rate. Schulte and Whitcomb (1973) stated that leaching of nutrients from cuttings under mist decreased rooting to some extent; this occurrence may be a limiting factor in the propagation of some species.

2.2.1.2 Fertilizer Uptake by Misting

Nutrient mist can be defined as the application of soluble fertilizer through the mist propagation system (Wott and Tukey 1965) to replace losses by leaching (Sharpe 1955) and to provide for growth of cuttings during propagation (Wott and Tukey 1973).

According to Wittwer and Teubner (1959), foliar nutrition offered advantages of more rapid and more efficient absorption and utilization as compared with nutrients applied to the rooting medium. These nutrients can become unavailable to cuttings due to utilization by microorganisms, or by leaching. Paparozzi and Tukey (1979) demonstrated that tissue contents of N, P and K increased after foliar application of these elements through the mist system at rates from 225 to 1,875 ppm of 23-8-14 soluble fertilizer. However, foliar injury was observed at rates higher than 750 ppm for all species studied. No relationship between cuticle thickness and nutrient uptake and susceptibility to foliar fertilizer injury was found (Paparozzi and Tukey 1979).

Wott and Tukey (1969) demonstrated that during the rooting period, chrysanthemum cuttings absorbed more than 95% of P through the foliage even though it was plentiful within the rooting medium. This evidence suggested that cuttings were not able to absorb sufficient nutrients from the rooting medium to meet their requirements. However, Sharpe (1955) observed that foliar application of KNO_3 to cuttings was of no significant benefit in increasing K content of leaves.

Variable response of cuttings to nutrient mist has been obtained depending upon the species: (a) rooting percentage

was increased in softwood cuttings of Philadelphus coronarius, Euonymus fortunei 'Vegetus', Ligustrum obtusifolium, Lonicera morrowii (Wott and Tukey 1965, 1967) and Buxus sempervirens (Sorensen and Coorts 1966, 1968; Wott and Tukey 1965, 1967); (b) rooting percentage was not affected in softwood cuttings of Forsythia intermedia (Wott and Tukey 1965, 1967), Ilex crenata microphylla (Sorensen and Coorts 1968) and lowbush blueberry (Hall and Aalders 1970); and (c) rooting percentage was decreased in softwood cuttings of Salix purpurea (Wott and Tukey 1965), Berberis thunbergii, Chaenomeles speciosa, Lonicera tatarica, Viburnum lantana (Wott and Tukey 1967) and Euonymus fortunei coloratus (Sorensen and Coorts 1966, 1968), hardwood cuttings of Pachysandra terminalis, Euonymus fortunei 'Vegetus', Taxus cuspidata, Hedera helix, Juniperus chinensis 'Sargentii', Vinca minor (Wott and Tukey 1965), Thuja plicata, Thuja occidentalis (Wott and Tukey 1967), Juniperus horizontalis plumosa and Taxus media (Sorensen and Coorts 1966, 1968), and soft and hardwood cuttings of several cultivars of Rhododendron (Keever and Tukey 1979).

The quality of the root system and changes in dry weight during the rooting period also showed wide variability (Hall and Aalders 1970; Keever and Tukey 1979; Sorensen and Coorts 1966, 1968; Wott and Tukey 1965, 1967).

In all species studied, N and P contents were higher in cuttings propagated under nutrient mist than in those of cuttings propagated under water mist (Wott and Tukey 1965, 1967), and these elements increased with higher rates of fertilizer (Keever and Tukey 1979; Sorensen and Coorts 1968). K content showed a variable response as a result of nutrient misting depending upon species (Sorensen and Coorts 1968; Wott and Tukey 1965, 1967). Keever and Tukey (1979) found no net uptake of K, Mg and Ca by rhododendron cuttings under nutrient mist.

Wott and Tukey (1967) stated that, especially when propagating softwood cuttings, nutrient mist had a positive effect on growth after rooting and, subsequently also after transplanting. Hall and Aalders (1970) found the same effect on blueberry cuttings. In contrast, cuttings under nutrient mist were frequently damaged, especially at higher fertilizer concentrations of 170 mg per liter of 23-8-14 soluble fertilizer (Keever and Tukey 1979); rooting was also consistently inhibited at the highest rates of 0.5 g per liter of 20-20-20 soluble fertilizer (Sorensen and Coorts 1966); and pathological and physiological disturbances occurred more frequently (Wott and Tukey 1967). An important problem of nutrient mist propagation was the growth of algae over the rooting medium (Wott and Tukey 1967). Coorts and Sorensen (1968) identified many species of bluegreen algae as well as some green algae growing

over the rooting medium and bench under nutrient mist.

Keever and Tukey (1979) concluded that nutrient mist during propagation appeared to be of no benefit especially to cuttings from stock plants with adequate nutrition.

2.2.2 Role of Rooting Medium

The rooting medium is an important factor in the initiation and subsequent growth of roots, especially in difficult-to-root species (Hartmann and Kester 1975).

2.2.2.1 Aeration

Zimmerman (1925) obtained better root growth of Salix cuttings in a medium with 15 to 33% of O_2 mixed with 85 to 67% N, respectively; CO_2 in concentrations up to 25% did not affect results significantly, provided that O_2 concentrations were between 25 and 33%. Rooting was not obtained with O_2 concentrations as high as 90 to 100% (Zimmerman 1925). According to Hitchcock (1928), good aeration was essential for the development of healthy roots from cuttings.

Kramer (1969) stated that water deficiency reduced root growth and increased suberization, and that excess water may cause deficiency in aeration by displacement of the air from the rooting medium. Long (1932) found that moisture content

and aeration of the rooting medium influenced the character, i.e. fibrousness, brittleness, slenderness, branching, of the roots produced by stem cuttings. Swanson and Davis (1977) working with Plectranthus australis found that under normal and deficient nutrient conditions, lack of aeration reduced root length of cuttings.

It has been shown that aeration influenced directly the availability of certain nutrient elements (Black 1964), affected the levels of ethylene (Kawase 1972), increased auxins (Phillips 1964), and decreased gibberellins (Reid and Crozier 1971) and cytokinins (Burrows and Carr 1969). Swanson and Davis (1977) postulated that the effect of a poor aeration was due to an increase of carbon dioxide and ethylene in the rooting medium.

Sokratova (1965), cited by Hamilton and Johnson (1978), found that combinations of peat and sand or peat and perlite, gave satisfactory results from the stand point of aeration. Similar results were obtained by Whitcomb et al. (1978) with peat and perlite in comparison with peat and bark having 56 and 36% air space, respectively.

2.2.2.2 Temperature

According to Albert (1975), extreme temperatures reduced elongation and sink capacity of roots as well as translocation

of substances from above-ground parts. Hartmann and Kester (1975) stated that temperature of rooting medium between 23° and 27°C at the base of cuttings were best for most species.

2.2.2.3 pH

The pH of the rooting medium has been demonstrated to be an important factor in nutrient uptake (Bassioni 1971; Munn and Jackson 1978). Hamilton and Johnson (1978) suggested that nutrients in the rooting medium were not utilized by cuttings, probably due to an early and rapid release of nutrients before development of root initials. Tukey and Mecklenburg (1964) showed that absorption of Ca, P and Sr from the rooting medium was increased in plants subjected to leaching by mist.

The pH of the rooting medium has been found to influence root initiation (Hamilton and Johnson 1978) and root growth (Albert 1975; Paul and Leiser 1968). Hitchcock and Zimmerman (1926) indicated that pH of the rooting medium could not be considered as a limiting factor in rooting. Smith (1926) showed that Coleus cuttings rooted in medium with pH between 4.0 and 9.2; the best and fastest root production occurred at pH 7.0 to 7.2. Raabe and Vlamis (1966), however, found no relationship between pH of the rooting medium and rooting of chrysanthemum cuttings. Dinter and Eaton (1976) stated that unfavorable pH levels did not account for observed harmful

effects of added fertilizers to the rooting medium. Hitchcock (1928) suggested that, in general, cuttings rooted better when the pH of the rooting medium was comparable to that of the natural habitat in which the mother plants grew best.

Hamilton and Johnson (1978) demonstrated that lower pH values resulting from addition of organic matter, such as peat moss, increased anion absorption by the rooting medium, thereby reducing leaching losses, especially of nitrates. The Ca concentration required for normal root growth was higher at lower pH values of the rooting medium (Paul and Leiser 1968). Higher doses of fertilizers, i.e. Osmocote added to the rooting medium decreased the pH as compared to the untreated control (Dinter and Eaton 1976).

2.2.2.4 Organic Matter

Hamilton and Johnson (1978) demonstrated that rooting medium containing peat moss had a greater retention capacity for nutrients, especially easily-leached nitrates; leaching of P and K were less affected by the presence of peat moss in the medium.

According to Paul and Smith (1966), the principal exchangeable ion in Canadian peat was H, present mainly as COOH and to a lesser extent as phenolic OH. They demonstrated that root length was highest with 38% Ca saturation of peat moss, and that

root number decreased linearly with increasing Ca saturation in chrysanthemum cuttings. Paul and Leiser (1968) found different results for other species, but, in general, percentage rooting, root length and root number decreased at extreme values of Ca saturation for most of the species studied. Furthermore, Raabe and Vlamis (1966) showed that root formation in chrysanthemum cuttings was prevented by a high Na:Ca ratio and, to a lesser extent, by a high K:Ca ratio in the rooting medium. Lee et al. (1976) demonstrated that Ca saturation also influenced root regeneration after transplanting.

Ward and Whitcomb (1977) stated that better quality liners was obtained during the rooting period when the medium was in small containers instead of in flats, because of less damage of the root system when transplanting to containers.

2.2.3 Role of Fertilizer in Rooting Medium

Soaking softwood cuttings in soluble fertilizer increased rooting percentage in about 10% of chrysanthemum and carnation cuttings (Kamp and Bluhm 1950), but had no effect on privet (Zimmerman 1958).

The addition of KNO_3 to the rooting medium showed no noticeable effect on rooting percentage, root number and root length of vine cuttings (Pearse 1943). Schulte and Whitcomb

(1973) noted a slight increase in rooting percentage of Juniperus chinensis and Ilex cornuta cuttings when micronutrients were added to the rooting medium. In contrast, Diver and Whitcomb (1981) found no significant effect of micronutrients on rooting and subsequent growth of cuttings of Pyracantha coccinea and Juniperus procumbens, although a positive trend was observed. Furthermore, the presence of micronutrients in the rooting medium increased growth of Juniperus procumbens cuttings after rooting, but did not affect those of Ilex crenata (Henderson and Whitcomb 1980). Daily applications of solutions containing even small quantities of Fe improved rooting of cuttings of peach almond hybrids and subsequent transplanting success (Bindra 1976).

Periodic applications of soluble fertilizers after sticking did not increase rooting percentage (Zimmerman 1958). However, increase in root growth was obtained with Ligustrum, Pyracantha and Taxus in comparison with untreated cuttings; no differences were observed in Cornus, Corylus, Spiraea and Viburnum (Zimmerman 1958).

2.2.3.1 Soluble Salts

Dinter and Eaton (1976) found significantly higher levels of soluble salts when fertilizers were present in the rooting medium. Furthermore, higher doses of fertilizers i.e. Osmocote

added to the rooting medium increased levels of soluble salts as compared to the untreated control (Johnson et al. 1981; Reavis et al. 1980).

It has been demonstrated that rooting media high in soluble salts tended to inhibit rooting (McGuire and Bunce 1970; Reavis et al. 1980; Ticknor 1980) and root elongation (Johnson et al. 1981). Hathaway (1976) stated that the emerging primary roots had little tolerance to high soluble salts levels. Kramer (1969) indicated that species varied widely in their tolerance to high soluble salts levels. The level of soluble salts in a medium depended upon the water-holding capacity and the cation exchange capacity (CEC) of that medium (Tisdale and Nelson 1975). Thus, a rooting medium with a high CEC, such as one rich in peat, can withhold higher fertilizer rates without significantly increasing soluble salts in comparison with one poorer in organic matter (Hamilton and Johnson 1978).

2.2.3.2 Controlled-Release Fertilizers

According to Williams (1980), controlled-release fertilizers are fertilizers capable of releasing plant nutrients over an extended period of time. Fertilizer release may result from chemical, physical, or biological differences among the materials (Maynard and Lorenz 1979). Common ways of controlling the nutrient release are: use of natural compounds such as hoof and

horn and blood meal; synthetic products of low water solubility such as magnesium ammonium phosphate (MagAmp), and isobutylidene diurea (IBDU); biodegradable organic compounds such as ureaforms; or the coating of soluble materials such as sulphur coated urea (SCU), and Osmocote (Sharma 1979).

Barron (1974) stated that the ideal characteristics of a controlled-release fertilizer were: (a) reasonable coincidence of release pattern with uptake pattern of the crop in question; (b) flexibility in release patterns to meet the differing requirements of various crops; (c) predictable release over a broad spectrum of conditions; (d) minimal influence of external factors; (e) no harm to plants and no residual effects; and (f) potential release of any micro- or macro-nutrients. However, controlled-release fertilizers are much more expensive than comparable soluble sources (Maynard and Lorenz 1979).

2.2.3.3 Osmocote

Matkin (1970) indicated that the unique feature of Osmocote as compared to other controlled-release materials was that all the fertilizer potentially available was in a soluble form. Maynard and Lorenz (1979) stated that the main advantage of Osmocote was the ample flexibility that can be obtained with regard to nutrients released, to release rate and to release period.

According to Lunt et al. (1961), the nutrient release mechanism of Osmocote was by diffusion where the external water passed through the membranes dissolving some of the fertilizer and creating a saturated solution with considerable osmotic pressure; the dissolved fertilizer materials diffused through the coating membranes out to the external solution due to the concentration gradient. After most of the fertilizer had diffused, the remaining solution was withdrawn from the capsule apparently by external suction (Lunt and Oertli 1962).

The rate of diffusion was found to be regulated by the thickness of the coating membranes (Oertli and Lunt 1962b), constituted mainly of dicyclopentadiene with glycerol ester (Sharma 1979), and by temperature. An increase from 10° to 20°C approximately doubled the diffusion rate (Oertli and Lunt 1962a). Nutrient release from Osmocote was relatively steady until about two thirds of the fertilizer had been released (Lunt et al. 1961).

The release rate was not affected by external pH of the solution (Oertli and Lunt 1962a), particle or capsule size (Williams 1980), and by moisture levels supporting plant growth (Lunt and Oertli 1962). Oertli and Lunt (1962b) stated that during the periods of constant release rates, the concentration of the solution inside the capsules remained saturated and thus

a constant diffusion gradient was maintained. Because of the high internal salt concentration, biologically tolerable salt concentrations of the external solution showed little effect on the concentration gradient, and also prevented attack by microorganisms (Oertli and Lunt 1962a, 1962b).

That external moisture had only minor effects on release suggested that water diffused into the capsules largely in the vapor phase (Barron 1974). The marked release decline observed at very low external moisture was due to a decreased transfer of water into the capsules and therefore a small gradient across the membranes (Lunt and Oertli 1962). Osmocote either incorporated or surface-applied gave similar results, provided that in the latter case it was kept moist at all times (Coleman et al. 1978).

It was found that the initial release of N mainly from NH_4NO_3 salt (Patel and Sharma 1977) was higher than that of P and K under similar conditions (Cochrane and Matkin, 1966). Furthermore, N release was independent of the medium, sand or peat, during the whole release period (Prasad and Woods 1971). Osmocote formulations of 3- to 4-month release gave more rapid initial release of nutrients than 8- to 9-month release formulations (Gibson et al. 1977; Patel and Sharma 1977).

Schulte and Whitcomb (1973) found that higher levels of

nitrates and K in the rooting medium due to the addition of Osmocote paralleled increased rooting in Ilex cornuta cuttings. Tissue analysis revealed higher levels of N, P and K in cuttings rooted in medium containing Osmocote (Johnson and Hamilton 1977; Paparozzi and Tukey 1979; Raviv and Regev 1980; Ward and Whitcomb 1976).

Positive effect of Osmocote added to the rooting medium on rooting response and/or subsequent growth of cuttings after rooting and/or transplanting has been demonstrated for a number of species such as Forsythia intermedia, Pachysandra terminalis, Viburnum plicatum (McGuire and Bunce 1970), Cotoneaster dammeri 'Skogholm' (Chong 1982b; Deen 1973), Symphoricarpos orbiculatus (Deen 1973), several cultivars of Rhododendron (Carney and Whitcomb 1981; Gouin 1974; Self and Pounders 1978) and of Chrysanthemum (Hoeven et al. 1979; Raviv and Regev 1980), Ilex crenata (Carney and Whitcomb 1981; Glenn et al. 1975; Ward and Whitcomb 1979), Ilex cornuta (Glenn et al. 1975; Richards and Whitcomb 1979; Self and Pounders 1978), Ilex fosteri (Glenn et al. 1975), Ligustrum japonicum (Glenn et al. 1975; Johnson and Hamilton 1977), Juniperus conferta (Johnson and Hamilton 1977), Euonymus fortunei, Lagerstroemia indica, Ligustrum vicaryi (Whitcomb et al. 1978), Buxus microphylla, Camellia japonica, Ilex renata, Ilex vomitoria, Ligustrum recurvifolia (Self and Pounders 1978), Juniperus chinensis (Richards and

Whitcomb 1980), Pyracantha coccinea (Carney and Whitcomb 1981) and Cotoneaster lucidus (Chong 1982b). In contrast, rooting response of cuttings was decreased (Dinter and Eaton 1976; McGuire and Bunce 1970; Ticknor 1980; Williams and Bilderback 1980) or not affected (Chong 1982b; Deen 1973; Glenn et al. 1975; Johnson and Hamilton 1977; Richards and Whitcomb 1980) by the presence of Osmocote in the rooting medium, depending upon species.

The algae problem was not observed when controlled-release fertilizers were added to the rooting medium (Glenn et al. 1975; McGuire and Bunce 1970; Schulte and Whitcomb 1973). Gibson et al. (1977) concluded that Osmocote formulations with the slowest initial release rate were best suited for incorporation into the rooting medium. Raviv and Regev (1980) found better rooting response of chrysanthemum cuttings when Osmocote was added to the rooting medium as compared to nutrient mist.

3. MATERIALS AND METHODS

3.1 General Procedures

3.1.1 Propagating Environment

Propagation experiments were conducted at Macdonald College, Quebec (45°25' North, 73°56' West) under intermittent mist provided with deflection type nozzles and controlled by electronic leaf (Mac-Penny, Plastic Engineers Ltd., Worthing, W. Sussex), either outdoor in shaded frames during the growing season or under greenhouse condition during winter. All benches were provided with bottom heat thermostatically set at 21°C at the root zone level (Fox 1972). In all experiments stock plants from which cuttings were taken were growing at Macdonald College Campus.

The rooting medium used in all experiments was Canadian sphagnum peat moss and horticultural grade perlite mixed in a proportion of 1:1 by volume. Osmocote controlled-release fertilizer of different formulations and/or at different rates were incorporated or surface-applied to the rooting medium depending on the experiment. After sticking cuttings into the rooting medium, Benlate 50% WP (methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate), (2 g per liter) was applied at a rate of 1.5 liter/m^2 of bench space to prevent against rotting of

cuttings. Thereafter, Captan 50% WP (cis-N-((trichloromethyl) thio)-4-cyclohexene-1,2-dicarboximide) or Benlate mixed as described above, was applied alternatively every week.

3.1.2 Rooting Evaluation

In each experiment, cuttings were evaluated according to the following parameters: (a) rooting percentage; (b) mean root length of each cutting within treatment; and (c) mean root number of each cutting within treatment. Rooting index visually rated from 0 to 5 (Dinter and Eaton 1976) as exemplified for Cotoneaster acutifolia (Fig. 1), callusing percentage, total root length of all cuttings within treatment, and root fresh and dry weight of all cuttings within treatment were also recorded.

3.1.3 Chemical Analysis

3.1.3.1 Plant Tissue

In all experiments samples of leaves or above-ground part of cuttings were taken for determination of total N, P, K and Ca. Each sample within a replicate was immediately rinsed in distilled water and then dried at 65°C for 36 to 48 hours in a vacuum oven (20 cm of mercury, Precision Thelco, Model 29, Chicago) (Greweling 1966; Piper 1944; Steyn 1959).

Dried tissue samples were ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, Pa.) to pass through a 40-mesh

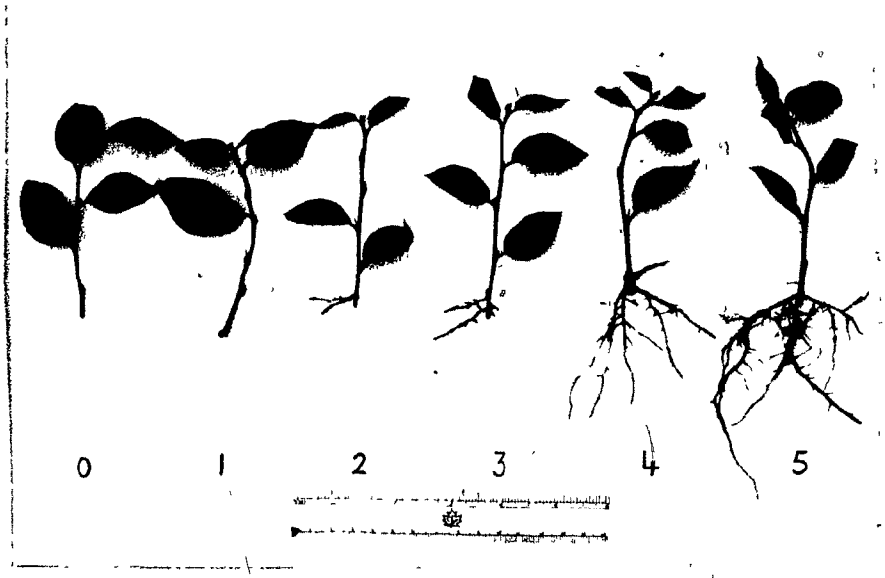


Fig. 1. Rooting Index in Cotoneaster acutifolia where 0= dead or alive but no sign of rooting activity; 1= callusing only, but no roots; 2= poor root system; 3= medium root system; 4= good and uniform root system; and 5= very extensive and well developed root system.

(0.42 mm sieve opening) wire screen. Ground samples were sealed in glass containers and stored at -5°C until used for mineral analyses. Prior to weighing portions for chemical analysis, ground samples were dried for 24 hours under conditions as described above.

Nitrogen

Total N was determined by the micro-Kjeldahl method (Association of Official Agricultural Chemists 1975).

(a) Reagents

H_2SO_4. Concentrated reagent, specific gravity 1.84, N-free.

K_2SO_4. Potassium sulfate reagent grade, N-free.

HgO. Mercuric oxide reagent grade, N-free.

H_3BO_3. Boric acid saturated solution (6.35 g in 100 ml of water at 30°C).

Sodium hydroxide-sodium thiosulfate solution. A mixture of 60 g of solid NaOH and 5 g of $Na_2S_2O_3 \cdot 5H_2O$ was made up to 100 ml with distilled water.

Indicator solution. A mixture of 2:1 by volume of 0.2% alcoholic methyl-red solution and 0.2% alcoholic methylene blue solution, respectively.

0.02 N HCl. 1.78 ml of HCl reagent 37.2% was made up to 1,000 ml with distilled water.

(b) Procedure

To 50 mg of dried ground tissue in a 30 ml regular Kjeldahl flask, 2 g of K_2SO_4, 50 mg of HgO and 2.5 ml of H_2SO_4 were added. This mixture was digested in presence of boiling chips for 1.5 hours. After cooling, solids were dissolved with 2 ml of distilled water and then transferred to a distillation apparatus, rinsing the Kjeldahl flask at least five times, each time with 2 ml of distilled water. The distillate was received in a 125-ml Erlenmeyer flask containing 5 ml of saturated H_3BO_3 solution and 3-4 drops of indicator solution. The distillate was then carefully mixed with 10 ml of $NaOH-Na_2S_2O_3$ solution; 15 ml aliquot was diluted to 50 ml with distilled water, and total N determined by titration with 0.02 N HCl to the first appearance of violet.

Phosphorus

The extraction of P from ground samples was done through the wet oxidation procedure (Jackson 1958).

(a) Reagents

HNO_3. Concentrated reagent, specific gravity 1.42.

Ternary mixture of acids. A mixture of concentrated HNO_3 reagent, concentrated H_2SO_4 reagent and 70-72% $HClO_4$, in a ratio of 10:1:4 by volume.

2 N HNO_3. 128 ml of concentrated HNO_3 reagent was diluted

to 1,000 ml with distilled water.

(b) Procedure

To 0.40 g of dried ground tissue in a 30 ml beaker was added 2 ml of concentrated HNO_3. The beaker was covered with a watch glass, heated at 100°C over a hot plate for 30 minutes, after which 3 ml of the ternary mixture of acids were added and the temperature increased to 180°C. The digestion was continued until the ash residue in the beaker was white and nearly dry. After cooling, 1 ml of 2 N HNO_3 was added to the residue and the extract quantitatively transferred to a 10 ml volumetric flask and made to volume with distilled water. The extract was stored in clear glass bottles at room temperature until used for P determination as described below.

P was determined using the molybdovanado phosphoric acid method described by Greweling (1966).

(a) Reagents

Mixed reagent. To 25 g of $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ (ammonium molybdate) dissolved in 300 ml of distilled water in a 1,000 ml volumetric flask, a solution of 1.25 g of NH_4VO_3 (ammonium metavanadate) in 500 ml of 5 N HNO_3 was added while stirring, then made up to volume with distilled water.

P standard solution. To 0.4393 g of KH PO in a 1,000 ml

volumetric flask 5 ml of concentrated HNO_3 reagent was added and then made to volume with distilled water.

(b) Procedure

Two milliliters of extract and 5 ml of the mixed reagent were added to a 25 ml volumetric flask, and made to volume with distilled water. Samples were allowed to stand overnight at room temperature for color development and then P was determined by comparing the transmitance at 470 mμ (Coleman Junior Spectrophotometer, Model 6 A, Maywood, Ill.) to a calibration curve prepared with solutions containing from 0 to 500 μg of P (0 to 5 ml of P standard solution). It should be noted that full color development occurred after 15 minutes and remained stable for several days (Greweling 1966).

Potassium and Calcium

The extraction for determination of K and Ca from ground samples was performed using the ammonium EDTA procedure (Baker and Greweling 1967; Greweling 1962).

(a) Reagents

0.1 M ammonium EDTA. To 292 g of ethylenedinitrilotetraacetic acid 500 ml of distilled water was added. Concentrated NH_4OH was then added until the acid was dissolved and then to excess to obtain a pH slightly above 9. The solution was allowed

to cool, diluted to 1,000 ml with distilled water, and stored in plastic containers at room temperature. This solution was diluted 1 to 10 with distilled water immediately before extraction.

K standards. Reference solution 1,000 µg K/ml (SO-P-351, Fisher Scientific Co.) was diluted with 0.1 M ammonium EDTA to 0.4 and 4.0 µg K/ml for the standard curve.

Ca standards. Reference solution 1,000 µg Ca/ml (SO-C-191, Fisher Scientific Co.) was diluted with 0.1 M ammonium EDTA to 0.4 and 4.0 µg Ca/ml for the standard curve.

(b) Procedure

To 25 ml of 0.1 M ammonium EDTA extractant 0.25 g of ground tissue was added. The mixture was shaken for 45 minutes on a reciprocating shaker (Eberbach Co., Ann Arbor, Michigan) at 270 to 280 strokes per minute, then filtered through No. 41 fast filter paper. The filtrate was diluted with 0.1 ammonium EDTA 1 to 100 before determination of K and Ca by atomic absorption spectrophotometry (Jarrell-Ash, Model 850, Fisher Scientific Co.) using the parameters shown in Table 1.

3.1.3.2 Rooting Medium

Samples (25 ml each) of wet rooting medium from the root zone area (2 to 7 cm depth) also were taken with the plant tissue samples at the time of rooting evaluation. The Osmocote

Table 1. Operating parameters for K and Ca determination.

Specifications	K	Ca
Lamp	hollow cathode	hollow cathode
Current	8 mA	15 mA
Wavelength	7665 Å	4227 Å
Spectral Bandpass	5 Å	2 Å
Flame	oxidizing	oxidizing
Fuel	acetylene	acetylene
Oxidant	air	nitrous oxide
Burner Head	10 cm slot	5 cm slot
Averaging Period	6 sec	4 sec
Standard Solute	KCl	$CaCO_3$

capsules were removed carefully from each sample of rooting medium, the sample allowed to air-dry, and stored at room temperature until used for determination of soluble salts (specific conductivity) and pH (Jackson 1958; Piper 1944).

In each experiment, samples of the rooting medium from all replications were pooled and readings determined from three air-dried sub-samples, each of 5 g. Each sub-sample was suspended in 50 ml of double-distilled water and intermittently shaken for 20 minutes in a reciprocating shaker as previously

described. The specific conductivity (soluble salts) of the suspension was determined with a conductivity meter (Markson Science Inc., Model 10, Del Mar, Ca.), allowing one minute before reading each sample for the temperature compensation thermistor to reach suspension temperature. The pH of the suspension was then determined with a Fisher Accumet, Model 220 pH meter. The double-distilled water was previously aerated by pouring it several times into beakers to bring into equilibrium the carbon dioxide content which could affect the pH determination (Piper 1944).

Although the instruments used were provided with temperature compensator, all readings of soluble salts and pH were made at the same temperature (23°). Because of the very high water holding capacity of the rooting medium, a hydrolitic ratio (Jackson 1958) of 1:10 medium:water was used instead of the more commonly used ratio of 1:5 (Piper 1944).

3.2 Experiments

3.2.1 Influence of Osmocote Application Method and Rate on Rooting of Three Shrubs

3.2.1.1 Cutting Preparation

On June 6 and 7, 1980, softwood cuttings (9-11 cm long) were taken from the following species: Euonymus alata (Thunb.)

Siebold.; Philadelphus coronarius L. 'Aureus'; and Weigela Thunb. 'Bristol Ruby'. All cuttings were taken from current season terminal growth of a single shrub of each species. The approximate age of these species was ten years. During cutting preparation, days were sunny and with average temperature of 23°C.

The lower 3 cm of cuttings were stripped of foliage, the basal ends treated with rooting hormone powder (0.1% IBA, Seradix No. 1), and cuttings immediately stuck (2.5 cm deep x 3 cm apart) in medium previously described, and placed under intermittent mist. In this experiment, the rooting medium was contained in wooden flats (41 cm long x 34 cm wide x 15 cm deep), each with a different experimental factor combination described below.

3.2.1.2 Osmocote Application Method and Rate

The rooting medium was treated with Osmocote 14-14-14 (3- to 4-month release) according to the application methods and rates indicated in Table 2.

Table 2. Osmocote 14-14-14 application method and rate in the rooting medium.

Application method	Application rate			
Incorporated (i= kg/m^3)	0	1 i	2 i	4 i
Surface-applied (s= kg/m^2)	0	0.15 s	0.30 s	0.60 s

Treatments 0.15 s, 0.30 s and 0.60 s are equivalent to $\frac{1}{2}$, 1 and 2 oz/ft^2. Treatments 1 i and 0.15 s actually contained the same quantity (20.9 g/flat) of Osmocote, as also treatments 2 i and 0.30 s (41.8 g/flat) and treatments 4 i and 0.60 s (84.6 g/flat).

The experiment was a 2x4 factorial in a randomized complete block design with four replications and 10 cuttings per experimental factor combination. Factor A was the two application methods, and factor B Osmocote rates as described above, the two factors being completely cross-classified (Steel and Torrie 1980).

Cuttings of Philadelphus and Weigela were evaluated on July 14 and 15, and those of Euonymus on July 21. Immediately after rooting evaluation, all leaves (5 to 9 g fresh weight per treatment) and rooting medium (25 ml) were sampled for chemical analysis according to procedures previously described.

Rooting parameters described under General Procedures and mineral contents of cuttings were subjected to analysis of variance. Differences among means were compared by the least significant difference (LSD) method (Steel and Torrie 1980). Correlation analyses of selected rooting parameters with each of the analyzed mineral constituents of the cuttings and also with

levels of soluble salts and pH of the rooting medium were conducted. Test of significance for polynomial regression to the second degree was also conducted for these data.

Temperature and rainfall data during the rooting period are shown in Appendix Fig. 1.

3.2.2 Influence of Releasing Time of Osmocote on Rooting of Cotoneaster acutifolia

3.2.2.1 Cutting Preparation

On August 14, 1980, semi-hardwood cuttings (9-11 cm long) of 10-year-old Cotoneaster acutifolia Turcz. were taken from current season terminal growth of a series of shrubs, one shrub per replication. During cutting preparation, it was cloudy with average day temperature of 18°C.

The lower 3 cm of cuttings were stripped of foliage, the basal ends dipped for five seconds in 20,000 ppm IBA dissolved in 75% ethanol, and cuttings immediately stuck (2.5 cm deep x 3 cm apart) and placed under intermittent mist.

3.2.2.2 Osmocote with Different Releasing Time

The rooting medium was amended with two different Osmocote formulations: 19-6-12 (3- to 4-month release) and 18-6-12 (8- to 9-month release), each of them applied according to rates

indicated in Table 3.

Table 3. Osmocote 19-6-12 (3- to 4-month release) and Osmocote 18-6-12 (8- to 9-month release) application rates.

Symbol	Osmocote rate
0	Control (no Osmocote added)
1 i	1 kg/m^3 incorporated
2 i	2 kg/m^3 incorporated
4 i	4 kg/m^3 incorporated
0.15 s	0.15 kg/m^2 surface-applied ($\frac{1}{2}$ oz/ft^2)
0.30 s	0.30 kg/m^2 surface-applied (1 oz/ft^2)
0.60 s	0.60 kg/m^2 surface-applied (2 oz/ft^2)

The experiment was a 2x7 factorial in a randomized complete block design with six replications and 15 cuttings per experimental factor combination. Factor A was the two Osmocote formulations, and factor B Osmocote applications as described in Table 3, the two factors being completely cross-classified (Steel and Torrie 1980). Each flat was subdivided into four sections by one inch styrofoam pieces. Each section was 34 cm long x 8 cm wide x 15 cm deep, each containing one experimental factor combination. Treatments 1 i and 0.15 s actually contained the same quantity (4.1 g/section) of Osmocote, as also treatments 2 i and 0.30 s (8.2 g/section), and treatments 4 i and

0.60 s (16.3 g/section).

Cuttings were evaluated between October 1 and 3. Immediately after rooting evaluation, leaves and rooting medium (25 ml) were sampled for chemical analysis as previously described. Because many of the leaves from the cuttings had fallen at this time, only leaves remaining on the cuttings were sampled and pooled together (1 to 3 g fresh weight) from all replications. Rooting parameters as previously described were subjected to analysis of variance. Differences among means were compared by LSD. Correlation analyses of selected rooting parameters and also pooled mineral constituents of cuttings with levels of soluble salts and pH of the rooting medium were conducted. Test of significance for polynomial regression to the second degree was also conducted for these data.

Temperature and rainfall data during the rooting period are shown in Appendix Fig. 2.

3.2.3 Relationship of Osmocote and Speed of Rooting in *Juniperus sabina*

3.2.3.1 Cutting Preparation

On February 18, 1981, evergreen cuttings (9-11 cm long) of 6-year-old *Juniperus sabina* L. were taken from terminal unbranched growth of a series of shrubs, one shrub per replication.

The basal end of cuttings were stripped of foliage and dipped for five seconds in 5,000 ppm IBA dissolved in 50% ethanol, and cuttings immediately stuck (2.5 cm deep x 2 cm apart) and placed under intermittent mist in unshaded frames (Nelson 1959). In this experiment, the medium was contained un fiber flats (18 cm long x 13 cm wide x 7 cm deep). The mist frames were located in a greenhouse kept at 24°C day temperature and 18°C night temperature from 5.30 PM to 8.30 AM.

3.2.3.2 Harvest Date and Osmocote Rate

Osmocote 18-6-12 (8- to 9-month release) was incorporated in the rooting medium at the following rates: 0 kg/m^3 (control), 2 kg/m^3 (2 i), 4 kg/m^3 (4 i) and 6 kg/m^3 (6 i). Cuttings were harvested and evaluated on three different dates: April 16, April 30 and June 4 (i.e. 57, 71 and 106 days after sticking, respectively).

This experiment was a split-plot in time arranged in a randomized complete block design with five replications and 10 cuttings per experimental treatment, one treatment per flat. Main plots were harvest dates and sub-plots were Osmocote rates described above.

Immediately after rooting evaluation, above-ground part of cuttings (8 to 12 g fresh weight per treatment) and rooting

medium (25 ml) were sampled for chemical analysis according to procedures previously described; in the case of K and Ca analysis, samples were left overnight for extraction with ammonium EDTA because of the slower release of Ca from the tissues of this species (Greweling 1966).

Rooting parameters were subjected to analysis of variance, as well as each of the analyzed mineral constituents of the cuttings. Differences among means were compared by LSD. Correlation analyses of selected rooting parameters with each of the analyzed mineral constituents and also with levels of soluble salts and pH of the rooting medium were conducted. Test of significance for polynomial regression to the second degree was also conducted for these data. Homogeneity of experimental error mean squares of the different harvest dates were tested by Bartlett's test (Steel and Torrie 1980).

3.2.4 Interaction of IBA-Osmocote on Rooting of Cotoneaster acutifolia

3.2.4.1 Cutting Preparation

On July 1, 1981, softwood cuttings of Cotoneaster acutifolia were taken as described in section 3.2.2.1. During cutting preparation it was cloudy with average day temperature of 21°C.

The lower 3 cm of cuttings were stripped of foliage, the

basal ends treated in IBA as described below, and cuttings immediately stuck (2.5 cm deep x 3 cm apart) and placed under intermittent mist in subdivided wooden flats as described in section 3.2.2.2.

3.2.4.2 IBA and Osmocote Treatments

At each rate of Osmocote (Table 4), cuttings were subjected to the following rooting hormone treatments:

5,000 ppm IBA dissolved in 75% ethanol, 5-second dip

20,000 ppm IBA dissolved in 75% ethanol, 5-second dip

0.3% IBA in powdered talc (Seradix No. 2)

The rooting medium was amended with Osmocote 18-6-12 (8- to 9-month release) applied according to rates shown in table 4.

Cuttings were harvested and evaluated on three different dates: August 4, August 14 and September 3 (i.e. 34, 44 and 64 days after sticking, respectively).

This experiment was a split-plot in time arranged in a randomized complete block design with four replications and 10 cuttings per experimental treatment. Main plots were harvest dates and sub-plots were two factor combinations, factor A being IBA treatments and factor B being Osmocote rates, as described in Table 4. The two factors were completely cross-classified.

Table 4. Osmocote 18-6-12 (8- to 9-month release) application rates.

Symbol	Osmocote rate
0	Control (no Osmocote added)
1 i	1 kg/m^3 incorporated
2 i	2 kg/m^3 incorporated
4 i	4 kg/m^3 incorporated
0.15 s	0.15 kg/m^2 surface-applied ($\frac{1}{2}$ oz/ft^2)
0.30 s	0.30 kg/m^2 surface-applied (1 oz/ft^2)
0.60 s	0.60 kg/m^2 surface-applied (2 oz/ft^2)

Immediately after rooting evaluation, leaves of cuttings (6 to 10 g fresh weight per treatment) and rooting medium (25 ml) were sampled for chemical analysis according to procedures previously described. Rooting parameters and also each of the analyzed mineral constituents of the cuttings were subjected to analysis of variance. Differences among means were compared by LSD. Correlation analyses of selected rooting parameters with each of the analyzed mineral constituents of cuttings treated in 0.3% IBA powder, and with levels of soluble salts and pH of the rooting medium were conducted. Test of significance for polynomial regression to the second degree was also conducted for these data. Homogeneity of experimental error mean squares of the different harvest dates were tested by Bartlett's test

(Steel and Torrie 1980).

Temperature and rainfall data during the rooting period are shown in Appendix Fig. 3.

4. RESULTS

4.1 Influence of Osmocote Application Method and Rate on Rooting of Three Shrubs

Rooting performance and mineral contents of Euonymus alata, Philadelphus coronarius 'Aureus' and Weigela 'Bristol Ruby' cuttings as influenced by method and rate of application of Osmocote 14-14-14 are presented in tables 5 to 7.

4.1.1 Application Method and Rate

Rooting percentage and root length were significantly higher ($P=0.05$) with incorporated Osmocote than with surface-applied Osmocote for cuttings of Euonymus, Philadelphus and Weigela (Tables 5 to 7). However, analysis of variance indicated significant interaction ($P=0.05$) for rooting percentage in Euonymus and Philadelphus and for root length in Philadelphus. Rooting index (data not presented) showed similar trends to root length. While root number was significantly higher with Osmocote incorporated for Euonymus (Table 5), Weigela showed no response with regard to this rooting parameter (Table 7). Root number was not recorded for Philadelphus.

Higher rates of Osmocote in the rooting medium, especially when surface-applied, resulted in decreases in rooting perform-

Table 5. Influence of Osmocote application method and rate on rooting performance and mineral content of Euonymus alata cuttings.

Application method	Application rate	Rooting performance			Mineral content (% DW basis)			
		Rooting percentage	Root length[a] (cm)	Root number	N (3.25)[b]	P (0.26)	K (0.92)	Ca (2.79)
Control (no Osmocote)	0	80	6.1	6.0	1.66	0.15	0.50	1.83
Incorporated (kg/m^3)	1	75	6.4	6.1	1.53	0.15	0.50	1.78
	2	58	4.3	4.2	1.64	0.15	0.55	1.78
	4	28	2.2	2.1	1.74	0.16	0.60	1.88
Surface-applied (kg/m^2)	0.15	28	2.0	2.1	1.81	0.17	0.58	1.85
	0.30	15	0.6	0.8	1.71	0.16	0.63	1.85
	0.60	10	0.5	0.5	1.99	0.19	0.68	1.93
LSD (P=0.05)								
Application method		11	1.4	1.1	0.12	NS	0.05	NS
Rate		15	2.0	1.5	NS	NS	0.07	NS
Interaction		22	NS	NS	NS	NS	NS	NS

[a] Mean root length of each cutting within treatment.

[b] Data in brackets represent the initial mineral contents at the start of the experiment. These data are not considered in statistical analysis.

NS Not significant.

Table 6. Influence of Osmocote application method and rate on rooting performance and mineral content of Philadelphus coronarius 'Aureus' cuttings.

Application method	Application rate	Rooting performance			Mineral content (% DW basis)			
		Rooting percentage	Root length[a] (cm)	Root number	N (3.60)[b]	P (0.36)	K (2.65)	Ca (1.70)
Control (no Osmocote)	0	98	4.7	--	1.95	0.13	1.15	1.00
Incorporated (kg/m^3)	1	98	6.0	--	1.99	0.13	1.08	0.95
	2	90	5.1	--	1.99	0.14	1.08	0.95
	4	75	3.7	--	1.99	0.14	1.20	1.00
Surface-applied (kg/m^2)	0.15	75	4.4	--	2.10	0.17	1.25	1.03
	0.30	40	2.1	--	2.30	0.19	1.40	1.13
	0.60	10	0.2	--	2.61	0.23	1.50	1.13
LSD ($P=0.05$)								
Application method		9	0.9	--	0.10	0.01	0.09	NS
Rate		13	1.2	--	0.15	0.02	0.12	NS
Interaction		18	1.7	--	0.21	0.03	0.17	NS

[a] Mean root length of each cutting within treatment.

[b] Data in brackets represent the initial mineral contents at the start of the experiment. These data are not considered in statistical analysis.

NS Not significant.

-- Data not recorded.

Table 7. Influence of Osmocote application method and rate on rooting performance and mineral content of Weigela 'Bristol Ruby' cuttings.

Application method	Application rate	Rooting performance			Mineral content (% DW basis)			
		Rooting percentage	Root length[a] (cm)	Root number	N (2.93)[b]	P (0.29)	K (1.53)	Ca (1.42)
Control (no Osmocote)	0	68	14.3	8.2	1.89	0.16	0.70	0.93
Incorporated (kg/m^3)	1	60	13.4	10.1	1.84	0.15	0.73	0.88
	2	53	13.2	9.2	2.07	0.16	0.83	1.03
	4	25	4.9	4.6	2.18	0.21	0.98	0.93
Surface-applied (kg/m^2)	0.15	30	5.2	5.2	2.42	0.20	0.90	1.03
	0.30	28	5.2	5.3	2.47	0.23	0.95	1.03
	0.60	23	3.1	3.7	2.33	0.24	0.98	0.95
LSD (P=0.05)								
Application method		13	4.1	NS	0.13	0.02	0.07	NS
Rate		19	5.7	NS	0.18	0.02	0.10	NS
Interaction		NS	NS	NS	0.26	NS	NS	NS

[a] Mean root length of each cutting within treatment.

[b] Data in brackets represent the initial mineral contents at the start of the experiment. These data are not considered in statistical analysis.

NS Not significant.

ance of cuttings as compared to the control (Tables 5 to 7) except for root number in Weigela (Table 7). Interestingly, however, Philadelphus responded differently from the other two species with increasing rates of Osmocote. In fact, increases in rooting percentage of incorporated Osmocote over surface-applied Osmocote decreased at higher rates of Osmocote for Euonymus and Weigela cuttings, but increased for Philadelphus (Fig. 2).

4.1.2 Mineral Contents of Cuttings

The contents of the elements supplied by Osmocote (N-P-K) were significantly higher ($P=0.05$) in cuttings of all species in medium in which Osmocote was surface-applied in comparison with incorporated Osmocote (Tables 5 to 7) except for P in Euonymus cuttings which showed no significant difference in content due to application method (Table 5). Ca content was not significantly different in cuttings of all three species (Tables 5 to 7).

While K content consistently increased in cuttings of the three species with increasing rates of Osmocote (Tables 5 to 7), N and P contents showed increases, especially with surface-applied Osmocote, only in cuttings of Philadelphus (Table 6) and Weigela (Table 7); Ca content was not influenced by Osmocote rate. In none of the Osmocote treatments studied did mineral contents reached the initial content in cuttings at the start of the

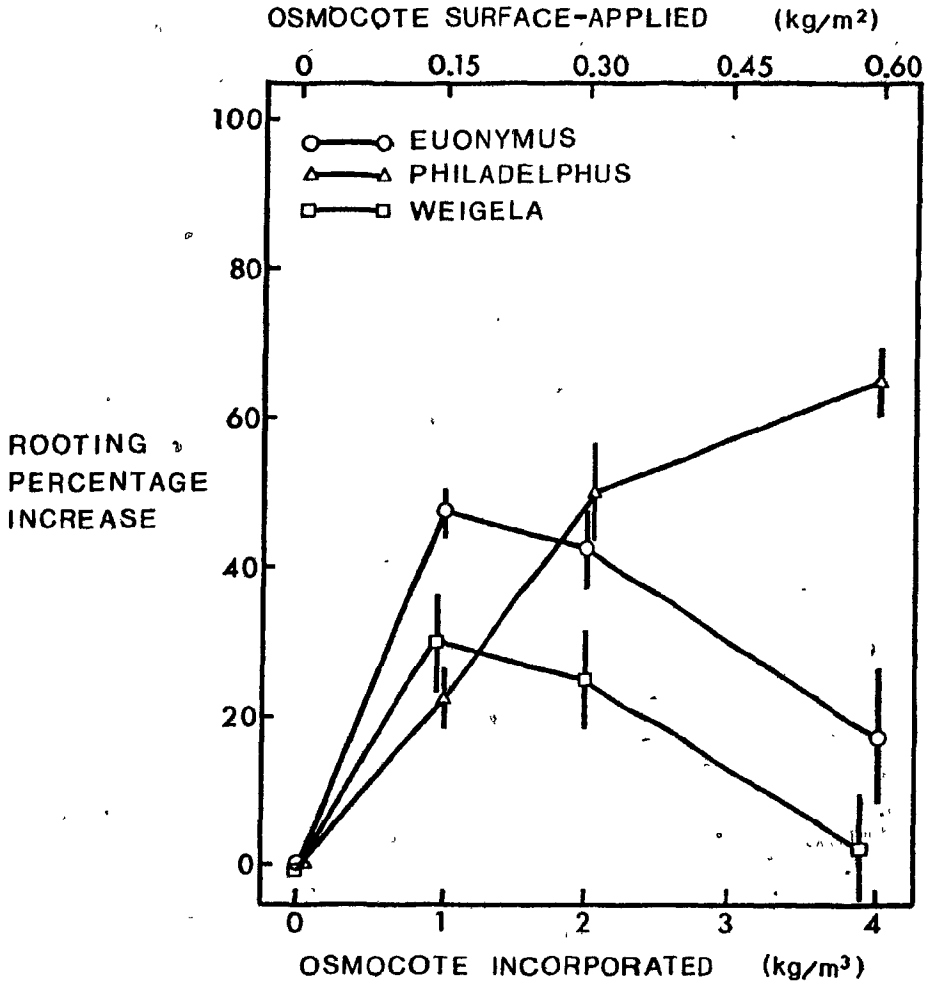


Fig. 2. Increase of rooting percentage of incorporated Osmocote over surface-applied Osmocote in Euonymus alata, Philadelphus coronarius 'Aureus' and Weigela 'Bristol Ruby' cuttings at different rates of Osmocote. Vertical bars represent standard errors.

experiment (Tables 5 to 7).

Table 8 shows results for correlation coefficients of each of the rooting parameters (rooting percentage, root length and root number) with contents of each of the mineral elements analyzed in the cuttings. Significant negative correlations ($\underline{P}$=0.05) were obtained in all the cases except between Ca content and rooting percentage and also root length in Weigela cuttings (Table 8). Second degree polynomial regression was not significant ($\underline{P}$=0.05) for all the cases presented in Table 8, except for root length and also root number versus K content of Euonymus cuttings.

4.1.3 Soluble Salts and pH of the Rooting Medium

Higher rates of Osmocote resulted in higher levels of soluble salts in the rooting medium in both incorporated and surface-applied methods (45 days after sticking), although levels of soluble salts were consistently higher in surface-applied treatments (Fig. 3). As indicated by standard errors in Fig. 3, the variability in soluble salts of surface-applied treatments was greater than of incorporated treatments. Higher rates of Osmocote tended to decrease pH of the rooting medium, especially when incorporated, as compared to untreated medium (Table 9).

Table 8. Correlation of rooting performance with mineral contents in cuttings.

Mineral content of cuttings	Rooting performance		
	Rooting percentage	Root length	Root number
	Euonymus alata		
N	-0.517**	-0.467**	-0.547**
P	-0.556**	-0.515**	-0.534**
K	-0.699**	-0.666**	-0.747**
Ca	-0.526**	-0.503**	-0.542**
	Philadelphus coronarius 'Aureus'		
N	-0.807**	-0.781**	--
P	-0.885**	-0.805**	--
K	-0.805**	-0.769**	--
Ca	-0.489**	-0.386*	--
	Weigela 'Bristol Ruby'		
N	-0.778**	-0.762**	-0.764**
P	-0.754**	-0.762**	-0.711**
K	-0.782**	-0.729**	-0.593**
Ca	-0.335	-0.290	-0.351*

*,** Significant correlation (*P=0.05; **P=0.01) based on 30 df.

-- Data not recorded.

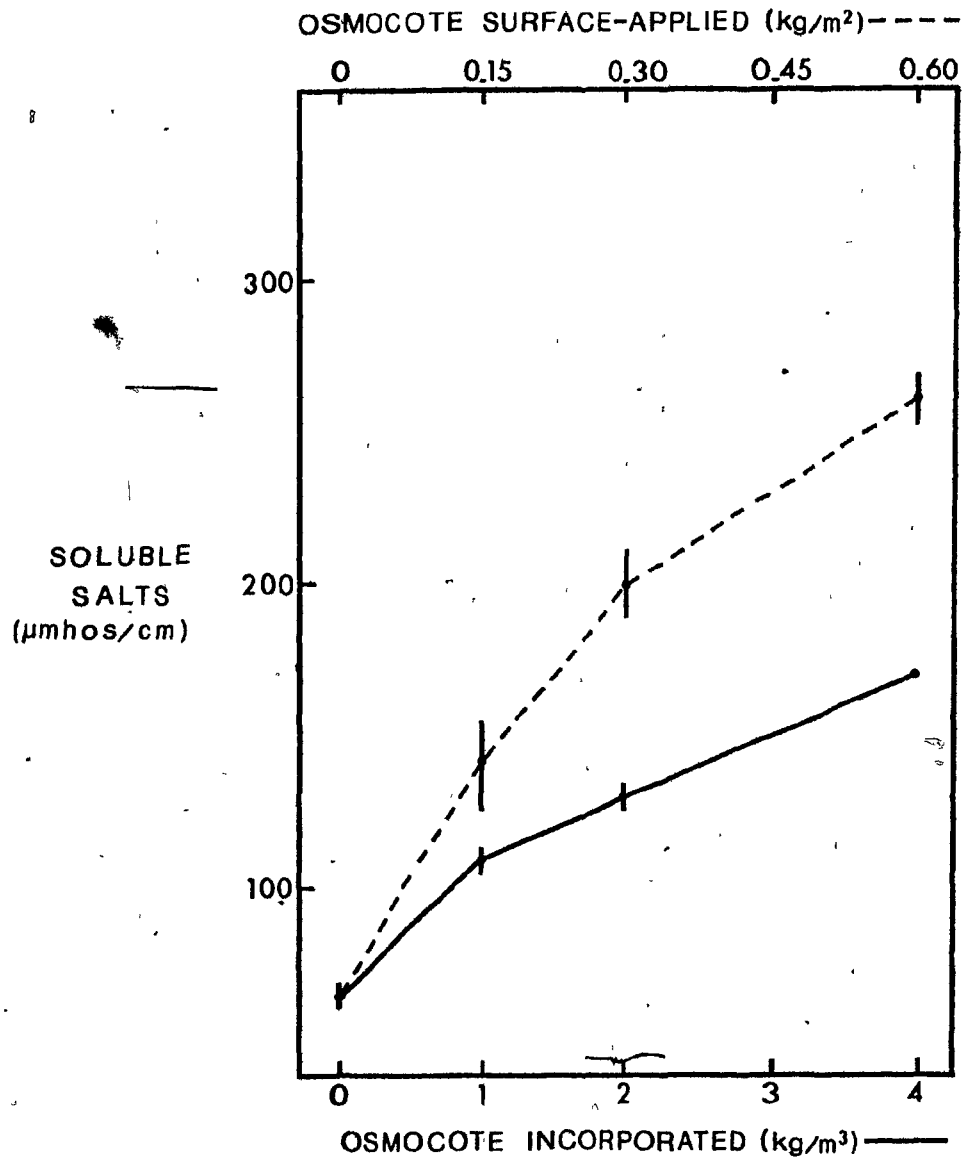


Fig. 3. Influence of Osmocote application method and rate on levels of soluble salts in the rooting medium. Vertical bars represent standard errors.

Table 9. Influence of Osmocote on pH of the rooting medium 45 days after sticking.

Osmocote rate (i, kg/m^3)[a] (s, kg/m^2)	pH of the rooting medium[b]
0	5.2 ± 0.00
1 i	4.9 ± 0.03
2 i	4.7 ± 0.06
4 i	4.6 ± 0.03
0.15 s	4.9 ± 0.00
0.30 s	4.9 ± 0.03
0.60 s	4.9 ± 0.06

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] Each datum is the mean of three replicates ± the standard error.

Correlation analysis of means of each of the rooting parameters (rooting percentage, root length and root number) with soluble salts in the rooting medium indicated significant negative values (P=0.05) in all three species (Table 10). However, correlation between pH of the rooting medium and the rooting parameters was consistent only for rooting percentage (Table 10). Significant negative correlation (P=0.05) was obtained between pH and soluble salts in the rooting medium (data not presented). Polynomial regression to the second degree was not significant (P=0.05) for all the cases presented in Table 10.

Table 10. Correlation of rooting performance of cuttings with soluble salts (SS) and with pH of the rooting medium.

Rooting medium	Rooting performance		
	Rooting percentage	Root length	Root number
	Euonymus alata		
SS	-0.902**	-0.883**	-0.895**
pH	0.810*	0.784*	0.791*
	Philadelphus coronarius 'Aureus'		
SS	-0.947**	-0.895**	--
pH	0.863*	0.746	--
	Weigela 'Bristol Ruby'		
SS	-0.864*	-0.849*	-0.770*
pH	0.762*	0.727	0.564

*,** Significant correlation (*P=0.05; **P=0.01) based on 6 df.

-- Data not recorded.

Table 11 shows results for correlation coefficients of contents of each of the mineral elements analyzed in cuttings with soluble salts and also with pH of the rooting medium. Levels of soluble salts in the rooting medium correlated significantly ($P=0.05$) with the mineral constituents in cuttings of the three species, except for contents of N and Ca in Weigela (Table 11). The pH of the rooting medium showed inconsistent correlation with the mineral constituents analyzed in cuttings (Table 11).

Table 11. Correlation of mineral contents of tissue cuttings with soluble salts and with pH of the rooting medium.

Mineral content of cuttings	Rooting medium	
	Soluble salts	pH
	Euonymus alata	
N	0.770*	-0.580
P	0.826*	-0.706
K	0.968**	-0.856*
Ca	0.757*	-0.519
	Philadelphus coronarius 'Aureus'	
N	0.892**	-0.843*
P	0.892**	-0.838*
K	0.866*	-0.757*
Ca	0.787*	-0.692
	Weigela 'Bristol Ruby'	
N	0.726	-0.676
P	0.898**	-0.762*
K	0.876**	-0.761*
Ca	0.225	-0.263

*,** Significant correlation (*P=0.05; **P=0.01) based on 6 df.

4.2 Influence of Releasing Time of Osmocote on Rooting of Cotoneaster acutifolia

Rooting performance of Cotoneaster acutifolia cuttings as influenced by releasing time formulation and rate of Osmocote 19-6-12 (3- to 4-month release) and Osmocote 18-6-12 (8- to 9-month release) are presented in Table 12.

4.2.1 Releasing Time and Rate

Rooting percentage and root length were significantly higher ($P=0.05$) with Osmocote 8- to 9-month release formulation than with Osmocote 3- to 4-month release formulation, while root number was not influenced by releasing time (Table 12). Corresponding data for rooting index and for total root length of all cuttings within treatment showed similar trends to root number (data not presented).

While increasing rates of incorporated Osmocote of the two formulations showed no significant influence on all rooting parameters, increasing rates of surface-applied Osmocote of the two formulations resulted in decreases in all rooting parameters as compared to the control (Table 12).

Table 13 shows results for correlation coefficients of means of each of the rooting parameters (rooting percentage,

Table 12. Influence of releasing time of Osmocote formulations and rate on rooting performance of Cotoneaster acutifolia cuttings.

Rate[a] (i,kg/m^3) (s,kg/m^2)	Rooting performance					
	Rooting percentage		Root length (cm)[c]		Root number	
	3-4[b]	8-9	3-4	8-9	3-4	8-9
0 (control)	65	65	2.7	2.7	5.9	5.9
1 i	50	68	2.3	2.6	5.0	5.4
2 i	63	71	2.6	3.2	6.0	5.9
4 i	64	70	2.7	3.4	5.6	5.9
0.15 s	49	55	2.0	2.1	4.4	3.8
0.30 s	51	57	1.9	2.6	3.8	4.4
0.60 s	37	53	1.1	2.0	3.4	4.1
LSD (P=0.05)						
Releasing time	8		0.4		NS	
Rate	15		0.8		1.8	
Interaction	NS		NS		NS	

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] 3-4= 3- to 4-month release; 8-9= 8- to 9-month release.

[c] Mean root length of each cutting within treatment.

NS Not significant.

Table 13. Correlation of rooting performance with mineral contents in Cotoneaster acutifolia cuttings.

Mineral content of cuttings	Rooting performance		
	Rooting percentage	Root length	Root number
N	-0.252	-0.222	-0.464
P	-0.333	-0.309	-0.409
K	-0.949**	-0.897**	-0.845**
Ca	0.257	0.232	0.360

*,** Significant correlation (*P=0.05; **P=0.01) based on 12 df.

root length and root number) with contents of N, P, K and Ca in the cuttings. Significant negative correlations (P=0.05) were obtained only between K content and all rooting parameters (Table 13). No significant second degree polynomial regression was obtained between any of the rooting parameters and mineral contents of Cotoneaster cuttings.

4.2.2 Soluble Salts and pH of the Rooting Medium

Higher rates of Osmocote resulted in higher levels of soluble salts in the rooting medium for both Osmocote formulations (50 days after sticking), although levels of soluble salts were consistently higher in the 3- to 4-month release formulation treatments (Fig. 4).

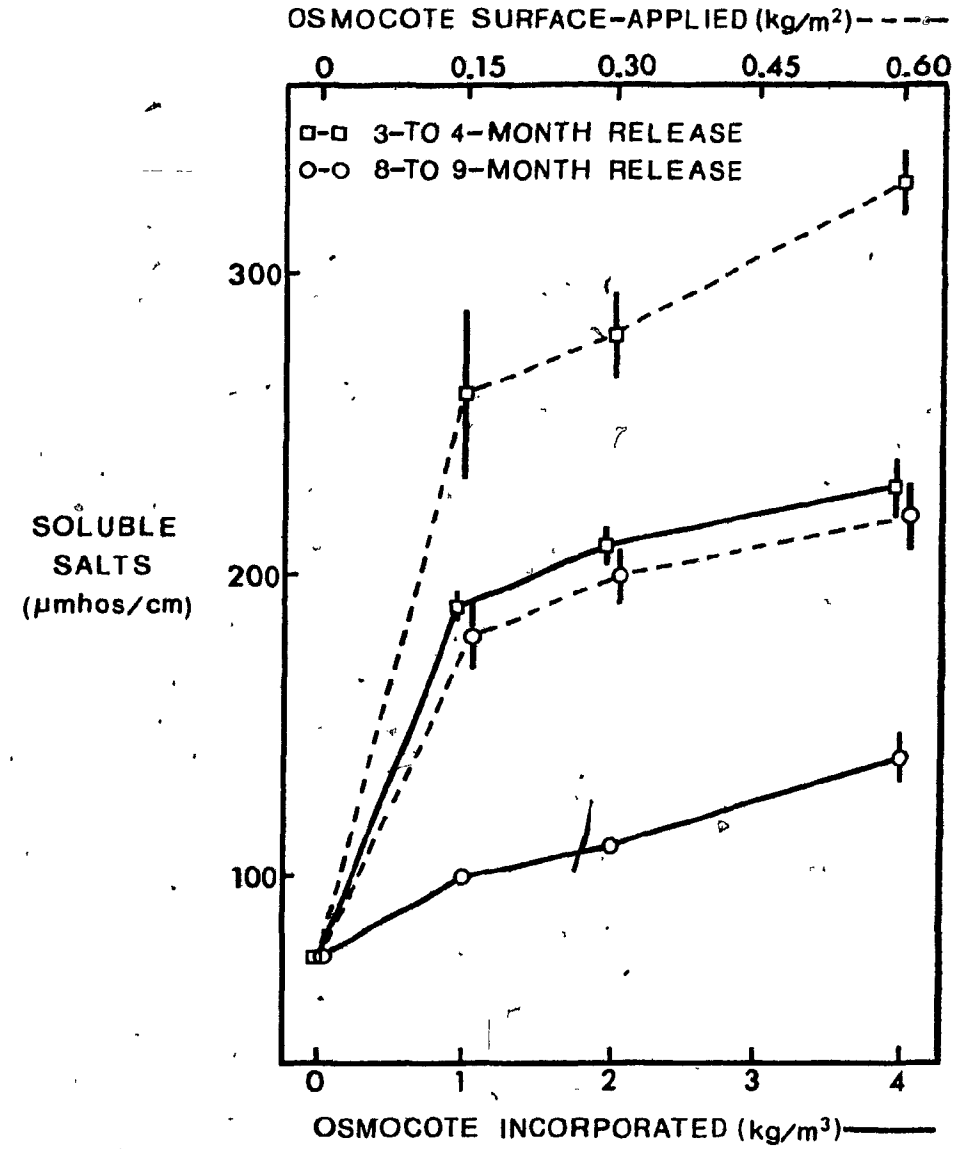


Fig. 4. Influence of Osmocote release time formulation and rate on levels of soluble salts in the rooting medium. Vertical bars represent standard errors greater than 6 μmhos/cm.

Table 14. Influence of Osmocote release time formulation and rate on pH of the rooting medium 50 days after sticking.

Osmocote rate (i, kg/m^3)[a] (s, kg/m^2)	pH of the rooting medium[b] with Osmocote formulation of	
	3- to 4-month release	8- to 9-month release
0	5.2 ± 0.00	5.2 ± 0.00
1 i	4.8 ± 0.03	4.7 ± 0.00
2 i	4.7 ± 0.00	4.6 ± 0.03
4 i	4.5 ± 0.03	4.7 ± 0.03
0.15 s	4.6 ± 0.10	4.7 ± 0.00
0.30 s	4.6 ± 0.00	4.7 ± 0.00
0.60 s	4.6 ± 0.06	4.7 ± 0.00

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] Each datum is the mean of three replicates ± the standard error.

In all cases the pH was lowered by the presence of Osmocote in the rooting medium, although no differences among treatments including Osmocote were obtained (Table 14).

Significant (P=0.05) negative correlations were obtained for means of each of the rooting parameters (rooting percentage, root length and root number) with soluble salts in the rooting medium, but not with pH (Table 15). Polynomial regression to the second degree was not significant (P=0.05) between soluble

Table 15. Correlation of rooting performance and also mineral contents of cuttings of Cotoneaster acutifolia with soluble salts and with pH of the rooting medium.

	Rooting medium	
	Soluble salts	pH
Rooting performance		
Rooting percentage	-0.816**	0.179
Root length	-0.776**	0.192
Root number	-0.722**	0.310
Mineral content of cuttings		
N	0.438	-0.329
P	0.731**	-0.618*
K	0.761**	-0.140
Ca	-0.146	-0.374

*,** Significant correlation (*P=0.05; **P=0.01) based on 12 df.

salts in the rooting medium and rooting performance of cuttings.

Significant negative correlation (P=0.05) was obtained between pH and soluble salts in the rooting medium (data not presented). Soluble salts in the rooting medium correlated significantly (P=0.05) only with P and K contents of Cotoneaster cuttings (Table 15).

4.3 Relationship of Osmocote and Speed of Rooting in Juniperus sabina

Rooting performance and mineral contents of Juniperus sabina cuttings rooted in medium at different rates of incorporated Osmocote 18-6-12 (8- to 9-month release) and harvested at three dates after sticking are presented in Table 16.

4.3.1 Harvest Date and Osmocote Rate

Rooting percentage, root length and root number of Juniperus cuttings increased significantly ($P=0.05$) with each harvest date (Table 16). Corresponding data for rooting index, total root length of all cuttings within treatment, and fresh and dry weight showed similar trends to root number (data not presented).

Notwithstanding the decreasing trend in rooting percentage in relation to higher rates of Osmocote, especially at the third harvest date (106 days after sticking), rates of Osmocote showed no significant difference with regards to this parameter, but had significant influence ($P=0.05$) on root length and root number. The interaction between harvest date and rate of Osmocote for both root length and root number is noteworthy; while there was a consistent decrease of root length and root number at the third harvest date (106 days after sticking), corresponding data for the two other harvest dates were less consistent (Table 16).

Table 16. Rooting performance and mineral contents of Juniperus sabina cuttings rooted in medium at different rates of incorporated Osmocote 18-6-12 and harvested at three dates after sticking.

Harvest date (Days after sticking)	Rate (kg/m^3)	Rooting performance			Mineral content (% DW basis)			
		Rooting percentage	Root length[a] (cm)	Root number	N (1.62)[b]	P (0.18)	K (1.00)	Ca (1.36)
57	0	20	0.3	1.0	1.29	0.13	0.60	1.32
	2	20	0.5	1.2	1.38	0.12	0.58	1.30
	4	8	0.1	0.2	1.27	0.13	0.66	1.36
	6	12	0.2	0.5	1.33	0.14	0.64	1.32
71	0	32	1.2	1.8	1.25	0.13	0.56	1.26
	2	20	0.5	0.8	1.26	0.14	0.58	1.28
	4	26	0.8	0.9	1.24	0.14	0.62	1.32
	6	36	1.1	2.1	1.31	0.15	0.56	1.34
106	0	88	5.6	5.3	1.20	0.12	0.36	1.40
	2	68	3.8	4.1	1.32	0.13	0.44	1.42
	4	56	2.6	1.7	1.29	0.13	0.48	1.44
	6	46	2.2	1.4	1.42	0.15	0.50	1.48
LSD (P=0.05)								
Harvest date		10	0.4	0.8	NS	NS	0.06	NS
Rate		NS	0.9	1.1	0.08	0.01	NS	NS
Interaction		NS	1.5	1.8	NS	NS	NS	NS

[a] Mean root length of each cutting within treatment.

[b] Data in brackets represent the initial mineral contents at the start of the experiment. These data are not considered in statistical analysis.

NS Not significant.

4.3.2 Mineral Contents of Cuttings

Except for K, mineral contents of cuttings did not vary significantly ($P=0.05$) during the rooting period. On the contrary, however, while increasing rates of incorporated Osmocote showed no influence on K content of cuttings, contents of N and P increased significantly with higher rates of Osmocote. Ca content was not influenced by Osmocote rate (Table 16).

Table 17 shows results for correlation coefficients of each of the rooting parameters (rooting percentage, root length and root number) with contents of each of the mineral elements analyzed in the cuttings. Similar to Cotoneaster (Table 13), significant negative correlations ($P=0.05$) were obtained only between K content and all the rooting parameters at the third harvest date (106 days after sticking) (Table 17). No correlations were obtained for the two other harvest dates (data not presented). Polynomial regression to the second degree between rooting performance and mineral contents of Juniperus cuttings was not significant.

4.3.3 Soluble Salts and pH of the Rooting Medium

Soluble salts increased more rapidly up to 57 days after sticking, generally plateauing or slightly increasing between 57 and 106 days after sticking (Fig 5). Furthermore, higher rates of Osmocote incorporated resulted in higher levels of

Table 17. Correlation of rooting performance with mineral contents in Juniperus sabina cuttings 106 days after sticking.

Mineral content of cuttings	Rooting performance		
	Rooting percentage	Root length	Root number
N	-0.200	0.080	0.040
P	-0.354	-0.197	-0.137
K	-0.814**	-0.658**	-0.571**
Ca	-0.073	-0.045	-0.118

*,** Significant correlation (*P=0.05; **P=0.01) based on 18 df.

soluble salts in the rooting medium with similar trends for the three harvest dates (Fig. 5). On the other hand, pH was observed to be consistently lower in the presence of Osmocote in the rooting medium as compared to the control on each of the three harvest dates and a pH increase in time was observed regardless of Osmocote rate (Table 18).

Significant correlations (P=0.05) were obtained for means of each of the rooting parameters (rooting percentage, root length and root number) with soluble salts and pH in the rooting medium only at the third harvest date (106 days after sticking) (Table 19). Test for second degree polynomial regression was not significant (P=0.05) for rooting performance of Juniperus cuttings as influenced by soluble salts in the rooting medium.

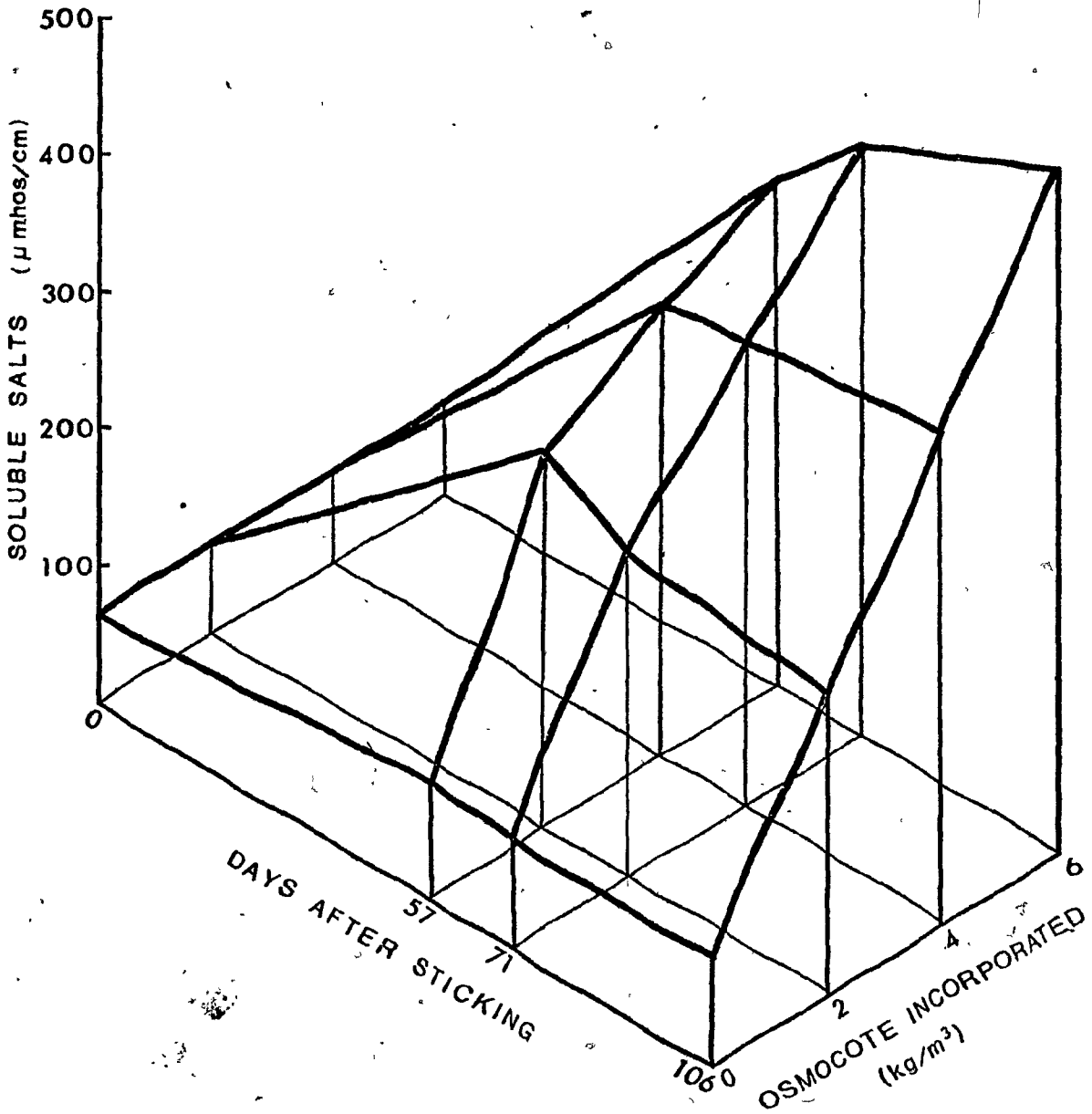


Fig. 5. Variation in levels of soluble salts in the rooting medium with different rates of incorporated Osmocote 18-6-12 sampled at three dates after sticking.

Table 18. Influence of incorporated Osmocote rate on pH of the rooting medium at three dates after sticking.

Osmocote rate (kg/m^3)	pH of the rooting medium [a] (days after sticking)			Mean
	57	71	106	
0	5.3 ± 0.03	5.4 ± 0.13	6.0 ± 0.13	5.6
2 i	5.0 ± 0.03	5.1 ± 0.12	5.6 ± 0.00	5.2
4 i	4.9 ± 0.06	5.0 ± 0.03	5.3 ± 0.06	5.1
6 i	4.9 ± 0.03	4.9 ± 0.06	5.2 ± 0.00	5.0

[a] Each datum is the mean of four replicates ± the standard error.

Significant negative correlations ($P=0.05$) were obtained between pH and soluble salts in the rooting medium for the three harvest dates (data not presented).

Soluble salts in the rooting medium correlated significantly ($P=0.05$) only with K and Ca contents of Juniperus cuttings at the third harvest date (Table 19). Similar relationships were not observed at the other two harvest dates.

Table 19. Correlation of rooting performance and also mineral contents of cuttings of Juniperus sabina with soluble salts and with pH of the rooting medium 106 days after sticking.

	Rooting medium	
	Soluble salts	pH
Rooting performance		
Rooting percentage	-0.986*	0.993**
Root length	-0.963*	0.999**
Root number	-0.963*	0.974*
Mineral contents of cuttings		
N	0.896*	-0.846
P	0.923	-0.829
K	0.958*	-0.996**
Ca	0.983*	-0.910

*,** Significant correlation (*P=0.05; **P=0.01) based on 2 df.

4.4 Interaction of IBA-Osmocote on Rooting of Cotoneaster acutifolia

Rooting performance of Cotoneaster acutifolia cuttings rooted in medium at different rates of Osmocote 18-6-12 (8- to 9-month release) and harvested at three dates after sticking are presented in Tables 20, 21 and 22 for each IBA treatment (5,000 ppm IBA ethanol solution, 20,000 ppm IBA ethanol solution and 0.3% IBA powder, respectively).

4.4.1 IBA Treatment and Osmocote Rate

While root length increased significantly ($P=0.05$) with each harvest date, rooting percentage and root number showed no significant difference in the case of cuttings treated with 5,000 and 20,000 ppm IBA (Tables 20 and 21). Corresponding data for total root length of all cuttings within treatment, and root fresh and dry weights showed similar trends to root length (data not presented). On the contrary, all rooting parameters increased significantly with each harvest date in cuttings treated with 0.3% IBA powder; there was significant interaction between harvest date and rate of Osmocote (Table 22).

The influence of rate of Osmocote on rooting performance depended on IBA treatment of cuttings. While increasing rates of incorporated Osmocote had no significant influence on all

Table 20. Rooting performance of Cotoneaster acutifolia cuttings treated in 5,000 ppm IBA, rooted in medium at different rates of Osmocote and harvested at three dates after sticking.

Harvest date (Days after sticking)	Rate (i,kg/m^3) (s,kg/m^2) [b]	Rooting performance: Rooting percentage	Root length [a] (cm)	Root number
34	0	30	1.0	2.3
	1 i	33	1.2	1.2
	2 i	28	0.5	1.0
	4 i	28	0.8	1.3
	0.15 s	10	0.3	1.0
	0.30 s	20	0.4	0.8
	0.60 s	30	0.9	1.6
44	0	40	1.3	4.4
	1 i	45	1.9	2.1
	2 i	38	1.6	2.6
	4 i	40	2.2	2.2
	0.15 s	13	0.5	0.6
	0.30 s	15	0.4	1.0
	0.60 s	45	2.1	3.3
64	0	35	2.5	1.9
	1 i	43	2.8	2.4
	2 i	43	1.8	2.2
	4 i	33	2.6	2.0
	0.15 s	25	1.3	1.2
	0.30 s	28	1.2	2.1
	0.60 s	45	3.5	2.7
LSD (P=0.05)				
Harvest date		NS	0.9	NS
Rate		16	0.9	1.1
Interaction		NS	NS	NS

[a] Mean root length of each cutting within treatment.

[b] i= Osmocote incorporated; s= Osmocote surface-applied.

NS Not significant.

Table 21. Rooting performance of Cotoneaster acutifolia cuttings treated in 20,000 ppm IBA, rooted in medium at different rates of Osmocote and harvested at three dates after sticking.

Harvest date (Days after sticking)	Rate (i,kg/m^3)[b] (s,kg/m^2)	Rooting performance		
		Rooting percentage	Root length (cm)	Root number
34	0	8	0.2	1.9
	1 i	13	0.4	1.2
	2 i	13	0.3	1.4
	4 i	8	0.3	0.2
	0.15 s	8	0.2	0.4
	0.30 s	13	0.2	1.2
	0.60 s	15	0.2	1.0
44	0	8	0.2	0.6
	1 i	10	0.3	0.5
	2 i	10	0.4	1.2
	4 i	20	0.6	2.7
	0.15 s	18	0.4	1.7
	0.30 s	18	0.6	1.6
	0.60 s	13	0.2	0.7
64	0	13	0.4	1.9
	1 i	25	1.4	1.4
	2 i	20	0.9	1.1
	4 i	35	1.3	4.6
	0.15 s	20	0.9	2.0
	0.30 s	28	1.4	2.4
	0.60 s	20	0.8	2.2
LSD (P=0.05)				
Harvest date		NS	0.3	NS
Rate		NS	NS	NS
Interaction		NS	NS	NS

[a] Mean root length of each cutting within treatment.

[b] i= Osmocote incorporated; s= Osmocote surface-applied.

NS Not significant.

Table 22. Rooting performance of Cotoneaster acutifolia cuttings treated in 0.3% IBA powder, rooted in medium at different rates of Osmocote and harvested at three dates after sticking.

Harvest date (Days after sticking)	Rate (i,kg/m^3)[a] (s,kg/m^2)	Rooting performance		
		Rooting percentage	Root length[b] (cm)	Root number
34	0	0	0.0	0.0
	1 i	5	0.1	0.1
	2 i	0	0.0	0.0
	4 i	0	0.0	0.0
	0.15 s	0	0.0	0.0
	0.30 s	0	0.0	0.0
	0.60 s	0	0.0	0.0
44	0	3	0.0	0.0
	1 i	8	0.2	0.1
	2 i	0	0.1	0.1
	4 i	0	0.0	0.0
	0.15 s	10	0.2	0.2
	0.30 s	0	0.0	0.0
	0.60 s	0	0.0	0.0
64	0	25	0.7	0.6
	1 i	65	2.3	1.7
	2 i	48	1.5	0.9
	4 i	8	0.2	0.1
	0.15 s	50	1.8	1.2
	0.30 s	15	0.3	0.2
	0.60 s	10	0.2	0.1
LSD (P=0.05)				
Harvest date		9	0.2	0.2
Rate		11	0.4	0.3
Interaction		18	0.7	0.5

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] Mean root length of each cutting within treatment.

rooting parameters in cuttings treated with 5,000 ppm IBA, increasing rates of surface-applied Osmocote resulted in decreases in all rooting parameters as compared to the control (Table 20). However, rate of Osmocote had no significant influence on all rooting parameters in cuttings treated with 20,000 ppm IBA (Table 21). On the other hand, lower rates of either incorporated or surface-applied Osmocote consistently showed increases in all rooting parameters as compared to the control in cuttings treated with 0.3% IBA rooting powder at the third harvest date (64 days after sticking) (Table 22).

In this experiment the IBA treatments also dramatically influenced the survival of Cotoneaster cuttings (Table 23). It is noteworthy that injury percentage was significantly higher (P=0.05) with the two treatments of IBA dissolved in ethanol as compared to the IBA rooting powder treatment in which there was little or no injury of cuttings (Table 23). Harvest date and Osmocote rate did not influence significantly the injury per-percentage of cuttings (Table 23).

4.4.2 Mineral Contents of Cuttings

Similar to Juniperus (Table 16), mineral contents of cuttings treated in 0.3% IBA powder only did not vary significantly (P=0.05) during the rooting period, except for K (Table 24). The contents of the elements supplied by Osmocote (N-P-K)

Table 23. Injury percentage of Cotoneaster acutifolia cuttings as influenced by IBA treatment and also by rate of Osmocote in the rooting medium after cuttings were harvested at three dates after sticking.

IBA treatment	Rate (i,kg/m^3)[a] (s,kg/m^2)	Harvest date (days after sticking) 34	44	64	Mean
5,000 ppm	0	23	20	33	25
(liquid)	1 i	48	35	50	44
	2 i	23	35	33	30
	4 i	43	45	50	46
	0.15 s	45	53	63	54
	0.30 s	58	58	68	61
	0.60 s	43	30	48	40
	Mean	40	39	49	43
20,000 ppm	0	55	68	60	61
(liquid)	1 i	73	43	55	57
	2 i	55	38	58	50
	4 i	60	48	53	54
	0.15 s	58	55	55	56
	0.30 s	55	40	58	51
	0.60 s	45	58	58	54
	Mean	57	50	57	55
0.3%	0	0	0	0	0
(powder)	1 i	0	0	0	0
	2 i	0	0	0	0
	4 i	0	0	0	0
	0.15 s	0	0	0	0
	0.30 s	0	0	0	0
	0.60 s	5	3	0	3
	Mean	0.7	0.4	0	0.4

LSD (P=0.05) IBA treatment= 5.8 Harvest date= NS
Rate= NS Interaction= NS

[a] i= Osmocote incorporated; s= Osmocote surface-applied.
NS Not significant.

Table 24. Mineral content of Cotoneaster acutifolia cuttings treated in 0.3% IBA powder, rooted in medium at different rates of Osmocote and harvested at three dates after sticking.

Harvest date (Days after sticking)	Rate (i, kg/m^3)[a] (s, kg/m^2)	Mineral content (% DW basis) N	P	K	Ca
		(2.54)[b]	(0.20)	(1.26)	(1.26)
34	0	2.05	0.18	1.05	0.93
	1 i	1.91	0.17	0.93	0.88
	2 i	2.11	0.18	0.95	0.95
	4 i	1.97	0.16	0.98	0.88
	0.15 s	1.87	0.16	1.00	0.85
	0.30 s	1.88	0.16	1.00	0.90
	0.60 s	2.10	0.19	1.03	0.98
44	0	1.93	0.14	0.80	0.88
	1 i	1.78	0.14	0.75	0.85
	2 i	1.84	0.15	0.75	0.93
	4 i	1.71	0.14	0.83	0.93
	0.15 s	1.89	0.15	0.73	0.88
	0.30 s	2.00	0.17	0.85	0.90
	0.60 s	1.87	0.16	0.83	0.90
64	0	1.84	0.15	0.68	1.10
	1 i	1.79	0.14	0.55	0.98
	2 i	2.08	0.16	0.63	1.08
	4 i	1.94	0.14	0.78	1.03
	0.15 s	1.99	0.15	0.60	1.00
	0.30 s	2.22	0.16	0.73	1.05
	0.60 s	2.18	0.16	0.75	1.03
LSD (P=0.05)					
Harvest date		NS	NS	0.10	NS
Rate		0.13	0.01	0.08	NS
Interaction		NS	NS	NS	NS

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] Data in brackets represent the initial mineral contents at the start of the experiment. These data are not considered in statistical analysis.

NS Not significant.

increased only with increasing rates of surface-applied Osmocote, but as in previous experiments, none of the Osmocote rates studied reached the initial mineral content of cuttings at the start of the experiment. Ca content was not influenced by Osmocote rate (Table 24).

Table 25 shows results for correlation coefficients of each of the rooting parameters (rooting percentage, root length and root number) with contents of each of the mineral elements analyzed in the cuttings. Similar to Juniperus (Table 17), significant negative correlations ($P=0.05$) were obtained only between K content and all the rooting parameters at the second and third harvest dates (44 and 64 days after sticking, respectively). Corresponding data for the first harvest date (34 days after sticking) showed no significant correlation (Table 25). Second degree polynomial regression was significant ($P=0.05$) for rooting percentage versus K content at the second harvest date, and for root number versus K content at the second and third harvest dates (44 and 64 days after sticking, respectively).

4.4.3 Soluble Salts and pH of the Rooting Medium

Soluble salts increased more rapidly up to 44 days, generally plateauing or decreasing slightly between 44 and 64 days for incorporated Osmocote (Fig. 6), or decreasing markedly between 44 and 64 days for surface-applied Osmocote (Fig. 7).

Table 25. Correlation of rooting performance with mineral contents in Cotoneaster acutifolia cuttings treated with 0.3% IBA powder, at 34, 44 and 64 days after sticking.

Mineral content of cuttings	Rooting performance								
	Rooting percentage			Root length			Root number		
	34 days	44 days	64 days	34 days	44 days	64 days	34 days	44 days	64 days
N	-0.157	-0.130	-0.355	-0.123	-0.225	-0.350	-0.173	-0.179	-0.463*
P	-0.092	0.032	-0.248	-0.025	-0.125	-0.252	-0.149	0.018	-0.358
K	-0.237	-0.545**	-0.823**	-0.224	-0.498**	-0.777**	-0.224	-0.551**	-0.762**
Ca	0.111	-0.214	0.232	0.064	-0.357	0.290	0.146	-0.264	0.070

*,** Significant correlation (*P=0.05; **P=0.01) based on 26 df.

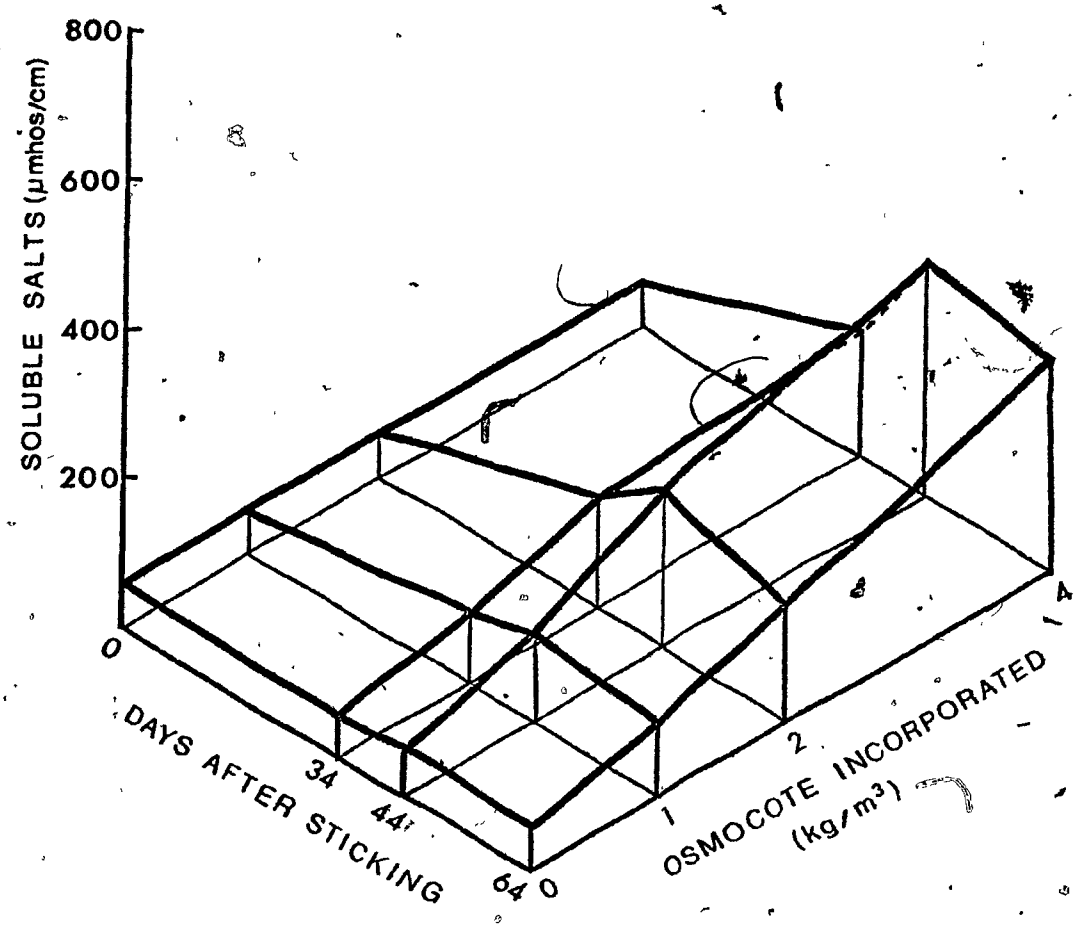


Fig. 6. Variation in levels of soluble salts in the rooting medium with different rates of incorporated Osmocote 18-6-12 sampled at three dates after sticking.

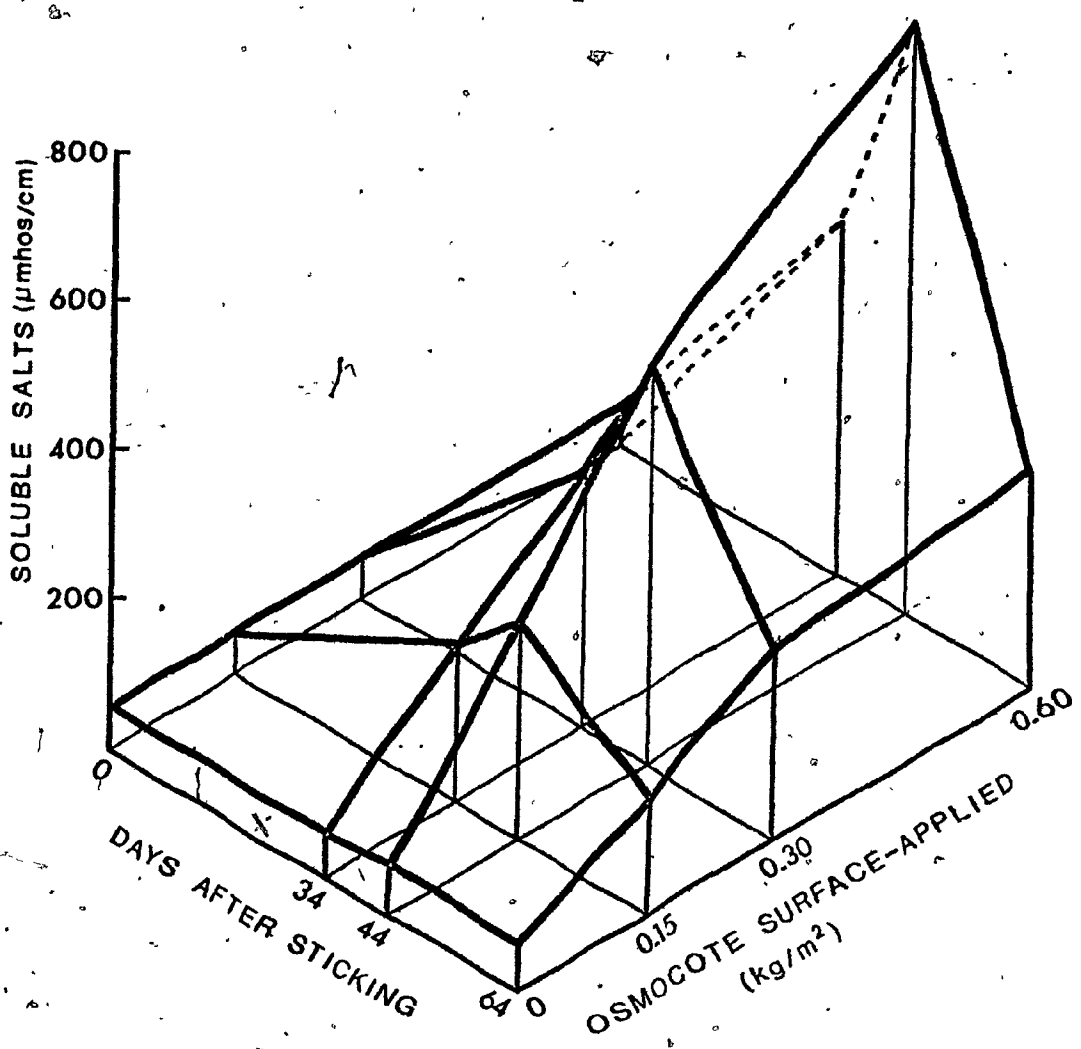


Fig. 7. Variation in levels of soluble salts in the rooting medium with different rates of surface-applied Osmocote 18-6-12 sampled at three dates after sticking.

Higher rates of Osmocote resulted in higher levels of soluble salts in the rooting medium with similar trends for the three harvest dates (Figs. 6 and 7). Higher levels of soluble salts were obtained with surface-applied Osmocote as compared to incorporated Osmocote (Figs. 6 and 7).

As in previous experiments (Tables 9, 14 and 18), pH of the rooting medium was lower in the presence of Osmocote. However, pH did not appear to increase in time (Table 26).

Significant ($P=0.05$) negative correlations were obtained for means of each of the rooting parameters (rooting percentage, root length and root number) with soluble salts in the rooting medium, but not with pH at the third harvest date, provided the control was not taken into account (Table 27). Similar correlations were not observed for the two previous harvest dates (data not presented). On the other hand, pH and soluble salts in the rooting medium correlated significantly ($P=0.05$) for the three harvest dates (data not presented).

Soluble salts in the rooting medium correlated significantly ($P=0.05$) only with K content of *Cotoneaster* cuttings at the third harvest date (64 days after sticking) (Table 27). Similar relationships were not observed at the other two harvest dates.

Table 26. Influence of Osmocote rate on pH of the rooting medium at three dates after sticking.

Osmocote rate (i,kg/m^3)[a] (s,kg/m^2)	pH of the rooting medium[b] (days after sticking) 34	44	64	Mean
0	5.3 ± 0.06	5.3 ± 0.04	5.4 ± 0.04	5.3
1 i	5.1 ± 0.08	5.2 ± 0.03	5.2 ± 0.03	5.2
2 i	4.9 ± 0.07	5.0 ± 0.04	5.1 ± 0.03	5.0
4 i	5.0 ± 0.03	4.9 ± 0.07	4.9 ± 0.01	4.9
0.15 s	4.8 ± 0.05	4.9 ± 0.04	4.9 ± 0.04	4.9
0.30 s	4.8 ± 0.04	4.9 ± 0.02	4.8 ± 0.03	4.8
0.60 s	4.8 ± 0.02	4.9 ± 0.07	4.8 ± 0.03	4.8

[a] i= Osmocote incorporated; s= Osmocote surface-applied.

[b] Each datum is the mean of six replicates ± the standard error.

Table 27. Correlation of rooting performance and also mineral contents of Cotoneaster acutifolia cuttings treated with 0.3% IBA powder, with soluble salts and with pH of the rooting medium, 64 days after sticking.

	Rooting medium	
	Soluble salts	pH
Rooting performance[a]		
Rooting percentage	-0.706 (-0.995**)	0.346
Root length	-0.671 (-0.988**)	0.289
Root number	-0.724 (-0.978**)	0.350
Mineral contents of cuttings[b]		
N	0.713	-0.680
P	0.270	-0.254
K	0.764*	-0.370
Ca	-0.157	0.494

*,** Significant correlation (*P=0.05; **P=0.01).

[a] Correlation coefficients based on 5 df. In brackets, correlation coefficients excluding data of the control based on 4 df.

[b] Correlation coefficients based on 5 df.

5. DISCUSSION

5.1 Influence of Osmocote Applications

A wide range of results has been reported with regard to the use of Osmocote in the rooting medium.

Beneficial effects have been reported for higher rates of Osmocote incorporated with Pachysandra terminalis (Osmocote 14-14-14 at 0 to 9.5 kg/m^3) (McGuire and Bunce 1970), with Cotoneaster dammeri 'Skogholm' and Symphoricarpos orbiculatus (Osmocote 14-14-14 and Osmocote 18-6-12, both at 0 to 3.2 kg/m^3) (Deen 1973), with Ilex cornuta 'Burfordi nana' (Osmocote 18-6-12 at 0 to 3.6 kg/m^3) (Richards and Whitcomb 1979); and also for higher rates of surface-applied Osmocote with several cultivars of Rhododendron obtusum (Osmocote 18-6-12 at 0 to 0.15 kg/m^2) (Gouin 1974), with Juniperus conferta (Osmocote 18-6-12 at 0 to 0.16 kg/m^2) (Johnson and Hamilton 1977), and with Cotoneaster dammeri 'Skogholm' and Cotoneaster lucidus (Osmocote 18-9-12 at 0 to 0.60 kg/m^2) (Chong 1982b).

On the other hand, negative influence has been reported for higher rates of incorporated Osmocote with Forsythia intermedia (Osmocote 14-14-14 at 0 to 9.5 kg/m^3) (McGuire and Bunce 1970), with Thuja occidentalis 'Pyramidalis', Cotoneaster

salicifolia floccosa, Rhododendron indicum and Ilex aquifolium (Osmocote 18-6-12 at 0 to 3.0 kg/m^3) (Dinter and Eaton 1976), with several cultivars of Chrysanthemum (Osmocote 15-12-15 at 0 to 4.0 kg/m^3) (Hoeven et al. 1979), with Rhododendron maximum and Kalmia latifolia (Osmocote 18-6-12 at 0 to 1.2 kg/m^3), (Williams and Bilderback 1980), and with three hybrids of Ilex cornuta (Osmocote 18-6-12 at 0 to 7.0 kg/m^3) (Tickner 1980); and also for higher rates of surface-applied Osmocote with Ligustrum japonicum (Osmocote 18-6-12 at 0 to 0.16 kg/m^2 and Osmocote 14-14-14 at 0 to 0.20 kg/m^2) (Johnson and Hamilton 1977).

Finally, no influence has been reported for higher rates of incorporated Osmocote with Viburnum plicatum tomentosum (Osmocote 14-14-14 at 0 to 9.5 kg/m^3) (McGuire and Bunce 1970), with Cupressocyparis leylandii and Prunus laurocerasus (Osmocote 18-6-12 at 0 to 3.0 kg/m^3) (Dinter and Eaton 1976), with Lagerstroemia indica, Ligustrum vicaryi and Euonymus fortunei 'Coloratus' (Osmocote 19-6-12, Osmocote 18-6-12 and Osmocote 18-5-11, all of them at 0 to 9.5 kg/m^3) (Gibson et al. 1977; Whitcomb et al. 1978) and with Juniperus chinensis 'Pfitzeriana aurea' (Osmocote 18-6-12 at 0 to 3.6 kg/m^3) (Richards and Whitcomb 1979); and also for higher rates of surface-applied Osmocote with Syringa villosa and Thuja occidentalis 'Pyramidalis' (Osmocote 18-9-12 at 0 to 0.60 kg/m^2) (Chong 1982b).

In investigations reported herein, incorporation of Osmocote into the rooting medium gave better rooting than surface-applied Osmocote in all species studied (Tables 5, 6, 7, 12, 20, 21 and 22) regardless of Osmocote rates and formulations. Similar comparisons between Osmocote application method to the rooting medium have not previously been reported by other researchers.

Slower releasing time formulations of Osmocote resulted in better rooting response of Cotoneaster acutifolia cuttings regardless of Osmocote rate and application method (Table 12), corroborating results obtained by Gibson et al. (1977) and by Whitcomb et al. (1978), even though they used higher rates (0 to 9.5 kg/m^3 incorporated).

Deen (1973) obtained similar results with Osmocote 14-14-14 (3- to 4-month release) and with Osmocote 18-6-12 (8- to 9-month release) for all species studied, with both Osmocote formulations incorporated at 0 to 3.2 kg/m^3. Johnson and Hamilton (1977) reported no difference in rooting of cuttings with Osmocote 14-14-14 (3- to 4-month release) and with Osmocote 18-6-12 (8- to 9-month release) surface-applied at 0 to 0.20 kg/m^2 and at 0 to 0.16 kg/m^2, respectively, in two different rooting media, namely sand alone and 1:1 (v/v) sand and peat moss.

Thus, it appeared that the main source of variation with regard to the use of Osmocote in the rooting medium were species and cultivars, although no relationship between any taxonomical characteristic and rooting response was observed. Other factors also seem to account for different response of cuttings to fertilizers applied in the rooting medium, such as type of Osmocote formulation (Table 12) (Gibson et al. 1977; Whitcomb et al. 1978), Osmocote application method and rate (Tables 5, 6, 7, 12, 20, 21 and 22), IBA treatments of cuttings (Tables 20, 21 and 22), rooting medium composition (Hamilton and Johnson 1978), incorporation of micronutrients (Coorts 1969; Gouin 1974), time of the year cuttings were taken (Dinter and Eaton 1976), and period between sticking and harvesting of cuttings (Tables 16, 20, 21 and 22) (Johnson and Hamilton 1977).

Thus, the influence of fertilizers such as controlled-release fertilizers in the rooting medium, must be determined empirically for each species or cultivar under particular rooting circumstances.

5.2 Soluble Salts

Various researchers (Dinter and Eaton 1976; Johnson and Hamilton 1977; McGuire and Bunce 1970; Ticknor 1980) have reported negative influence of fertilizers in the rooting medium

on rooting performance of cuttings, but none has shown evidence of direct mathematical relationships (i.e. correlations) of rooting performance with levels of soluble salts as in the present study (Tables 10, 15, 19 and 27). Dinter and Eaton (1976) suggested that the presence of fertilizers in the rooting medium induced a physiological response that either inhibited rooting or produced necrosis.

McGuire and Bunce (1970) indicated the importance of using controlled-release fertilizers to minimize potential dangers of soluble salts in medium that might retard rooting. Dinter and Eaton (1976), using a rooting medium similar to that used in investigations reported herein, obtained significantly higher levels of soluble salts with the use of several formulations of soluble fertilizers and of Osmocote incorporated into the rooting medium. They obtained lower rooting percentage of cuttings of Thuja occidentalis 'Pyramidalis', Cotoneaster salicifolia floccosa, Rhododendron indicum and Ilex aquifolium in these treatments but did not correlate these data with soluble salts levels in the rooting medium.

Similar to results reported by Simpson et al. (1975), surface-applied Osmocote resulted in consistently higher levels of soluble salts in the medium than incorporated Osmocote at each rate (Figs. 3, 4, 6 and 7) probably due to a higher proportion

of fertilizer per unit volume of medium in Osmocote surface-applied treatment, and also to higher leaching losses from the rooting medium with incorporation (Waters 1960). These reasons also probably account for the greater variability in soluble salts readings of surface-applied treatments as compared to incorporated ones (Figs. 3 and 4).

The increasing levels of soluble salts with increasing rates of surface-applied Osmocote (Figs. 3, 4 and 7) are in accordance with results obtained by Johnson et al. (1981) and by Chong (1982b). An important consideration is that Chong (1982b) used a 1:1 (v/v) perlite and turface rooting medium with very low CEC and much lower water holding capacity than the 1:1 (v/v) peat moss and perlite medium used in the experiments reported herein (section 3.1.1). The difference between the levels of soluble salts obtained by Chong (1982b) and those shown in Figs. 3, 4 and 7, corroborates data reported by Hamilton and Johnson (1978) indicating a greater retention of mineral salts in media containing organic matter. According to Tisdale and Nelson (1975), CEC and water holding capacity are two of the most important factors influencing directly the levels of soluble salts in the rooting medium.

Results for soluble salts levels obtained with surface-applied Osmocote 14-14-14 (Fig. 3) and with surface-applied

Osmocote 18-6-12 (Figs. 4 and 7) agree with data reported by Hamilton and Johnson (1978) except for the control (no Osmocote added) which was slightly lower, although not statistically significant from Osmocote treatments. This contrasted with marked differences between the control and Osmocote treatments shown in Figs. 3, 4 and 7. High levels of soluble salts for the control in the experiment reported by Hamilton and Johnson (1978) was due to the addition of micronutrient mixtures to the rooting medium.

Although different rates of Osmocote gave different levels of soluble salts, the similarity in trends of soluble salts versus time at each rate of Osmocote (Figs. 5, 6 and 7) are in agreement with findings reported by Patel and Sharma (1977).

In an experiment without use of mist, Reavis et al. (1980) reported levels of soluble salts of 650 to 900 µmhos/cm for high Osmocote 18-6-12 treatment of 5.3 kg/m^3 and 400 to 500 µmhos/cm for low Osmocote treatment of 1.8 kg/m^3, two months after incorporation into a 2:1:1 bark/peat moss/perlite medium under average conditions of 6°C night and 16°C day temperatures. In the present experiment (Fig. 5) with approximately similar rates of Osmocote 18-6-12 and with use of misting, lower levels of soluble salts were obtained. This may be due to (a) the lower proportion of organic matter in the medium (1:1 peat moss

and perlite) and therefore a lower retention of soluble salts (Hamilton and Johnson 1978; Prasad and Woods 1971; Tisdale and Nelson 1975), and (b) to higher leaching of salts from the medium with mist (Ticknor 1980). This occurred in spite of the higher average temperatures during the experiment reported herein (greenhouse condition of 18°C night and 24°C day temperatures, section 3.2.3.1).

Chong (1982b) showed that increasing rates (0 to 0.6 kg/m^2) of surface-applied Osmocote 18-9-12 (8- to 9-month release) increased rooting performance in Cotoneaster lucidus in terms of rooting percentage, root length and root number, and in Cotoneaster dammeri 'Skogholm' in terms of root number only. The levels of soluble salts in the rooting medium increased with increasing rates of Osmocote, although the actual levels of salts were relatively low, never exceding 114 µmhos/cm at the highest Osmocote level (Chong 1982b). With lower levels of soluble salts (Figs. 6 and 7), cuttings of Cotoneaster acutifolia that remained for a longer period in the rooting bench (64 days) due to the 0.3% IBA powder treatment, showed significantly higher rooting performance for the lower rates of Osmocote 18-6-12 (8- to 9-month release) as compared to the control (Table 22). In the experiment reported by Chong (1982b) it is noteworthy that his cuttings were treated also with 0.3% IBA (Stim-Root No. 2) rooting powder. The similarity of these results in contrast to the rooting de-

crease of Cotoneaster acutifolia and other species treated with liquid IBA, suggests that the form of IBA applied to cuttings may affect their response to soluble salts in the rooting medium. Although possible reasons for this observation is obscure, it is noteworthy that cuttings treated with this form of IBA tend to root slower than cuttings of similar species treated with liquid IBA (Tables 20, 21 and 22).

No direct relationships between IBA and Osmocote treatments were observed in experiments reported herein (Table 23). Chong 1981, 1982a) reported basal injury of cuttings treated with liquid IBA of high concentrations (20,000 to 40,000 ppm), although prolific and optimum rooting occurred above the injured portion in Cotoneaster acutifolia, Malus 'Hopa' and Taxus cuspidata cuttings. Dinter and Eaton (1976) reported necrosis of cuttings treated with 0.8% IBA powder, probably due more to the fertilizers present in the rooting medium than to IBA treatment.

Species and cultivars vary in their tolerance to levels of soluble salts (Kramer 1969). Johnson and Hamilton (1977) reported that Ligustrum japonicum was more sensitive than Juniperus conferta to high levels of soluble salts in the rooting medium, inducing actual damage of newly formed roots. While all species studied herein showed significant negative linear correlation between rooting performance of cuttings and levels of soluble

salts in the rooting medium (with the exception of Cotoneaster acutifolia when treated with Seradix No. 2, 0.3% IBA rooting powder as discussed above), the nature of the response was somewhat different between species (Figs. 8, 9 and 10).

Deen (1973) indicated that Osmocote applied to the rooting medium may have a useful part to play, particularly in the propagation of quicker-rooting species. While rooting percentage of quicker-rooting species, such as Euonymus alata, Philadelphus coronarius 'Aureus' and Weigela 'Bristol Ruby', showed lower tolerance to soluble salts (larger values of slope of the regression curves), the reverse was true for slower-rooting species, such as Cotoneaster acutifolia and Juniperus sabina (smaller values of slope of the regression curves) (Table 28 and Fig. 8). Interestingly, the corresponding slopes for root length and root number of all species were consistently lower than those found for rooting percentage versus soluble salts (Table 28 and Figs. 9 and 10). This evidence suggests that, unlike root length and root number which seem to reflect more the root development capacity of cuttings, the degree of rooting percentage, which reflects more the capacity for root initiation, seems to be more closely associated with the slope of this parameter in relationship with levels of soluble salts in the rooting medium. This corroborates findings that high levels of soluble salts tend to have greater inhibition effect on root initiation

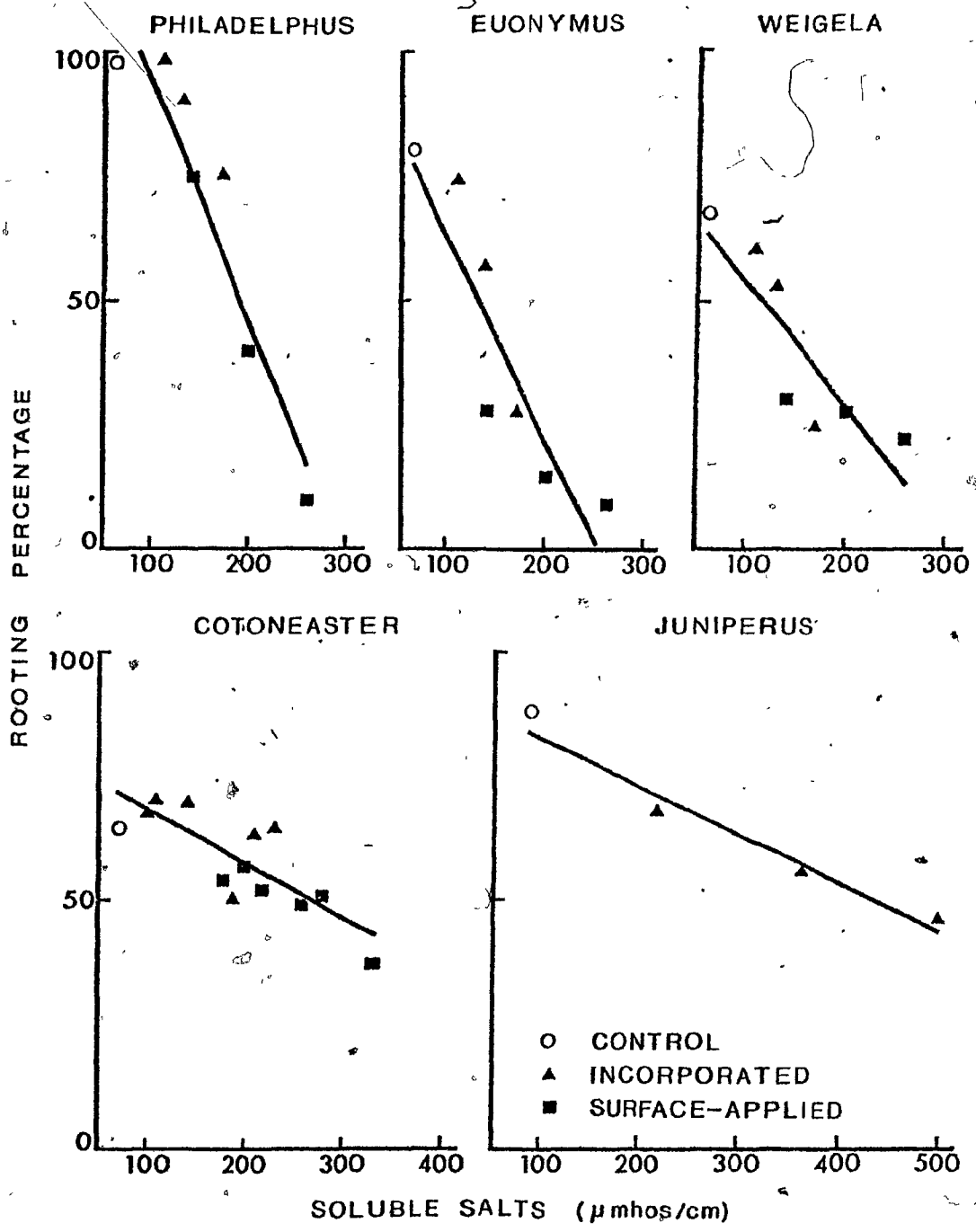


Fig. 8. Regression curves between rooting percentage of cuttings and soluble salts in the rooting medium.

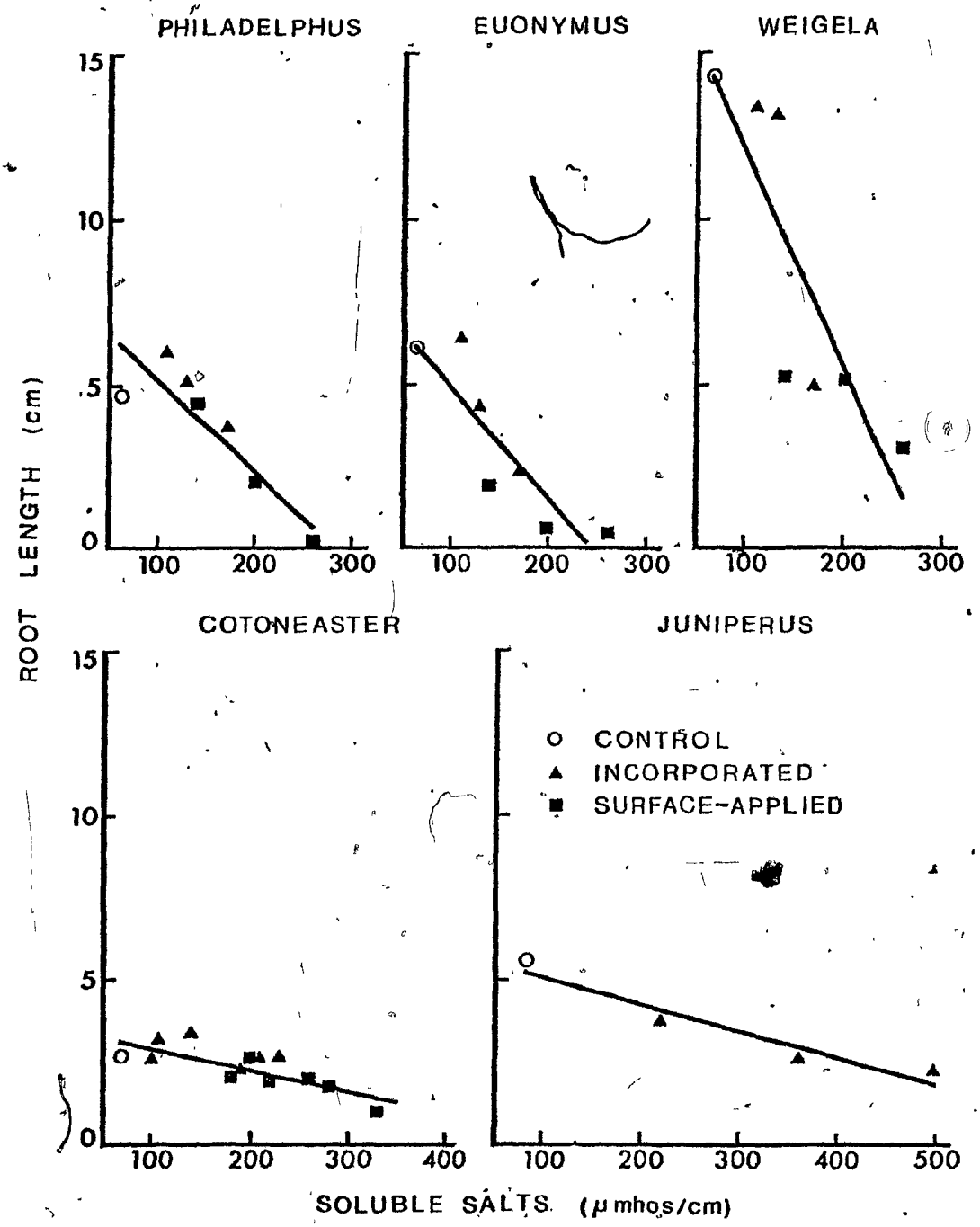


Fig. 9. Regression curves between root length of cuttings and soluble salts in the rooting medium.

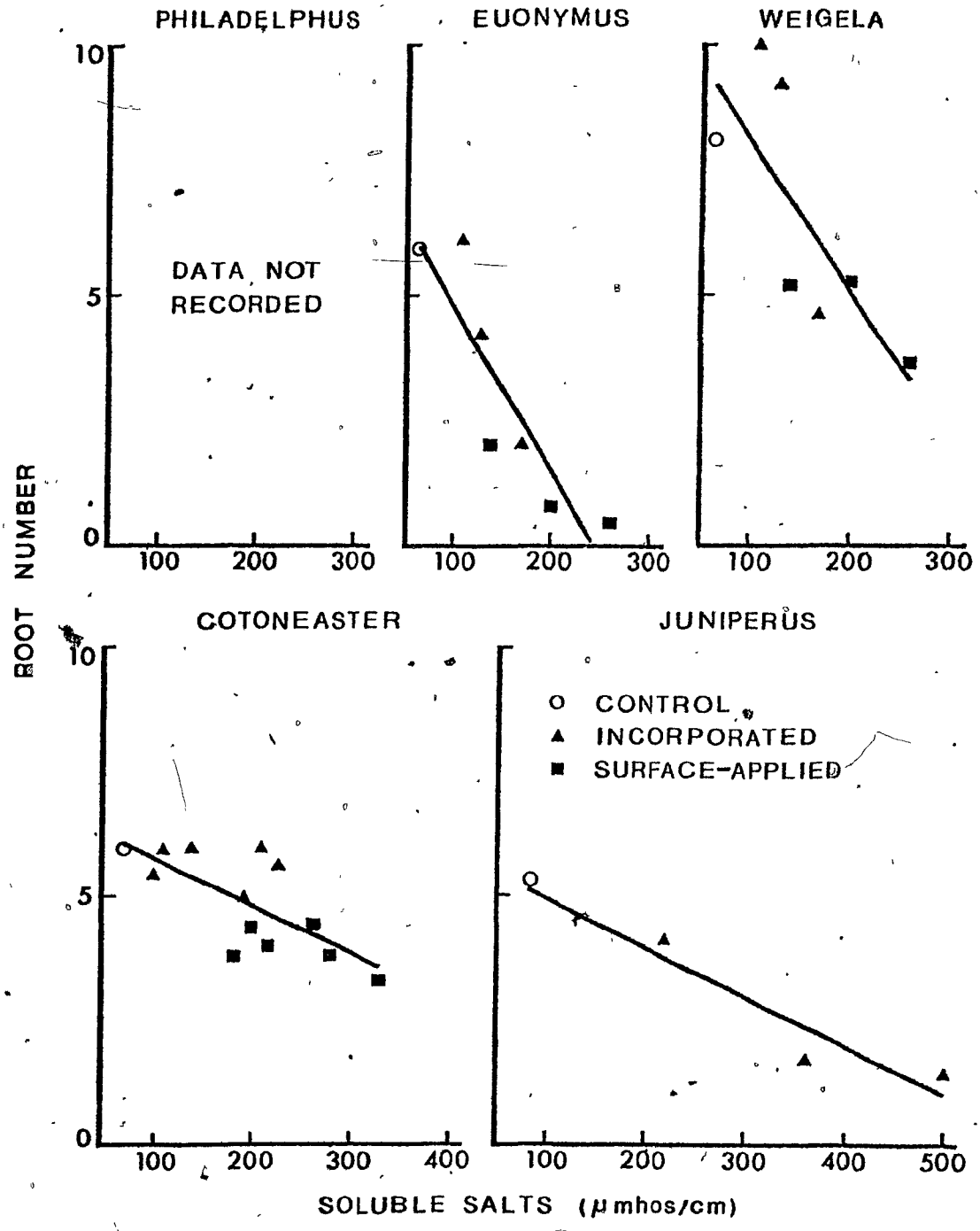


Fig. 10. Regression curves between root number of cuttings and soluble salts in the rooting medium.

Table 28. Predicted intercepts and slopes of the regression curves between soluble salts of the rooting medium and rooting performance of cuttings.

Predicted values for	Rooting performance		
	Rooting percentage	Root length	Root number
	Euonymus alata		
Intercept	104.050	8.380	8.150
Slope	-0.406	-0.034	-0.033
	Philadelphus coronarius 'Aureus'		
Intercept	144.060	8.020	--
Slope	-0.487	-0.028	--
	Weigela 'Bristol Ruby'		
Intercept	79.570	18.470	11.210
Slope	-0.253	-0.065	-0.030
	Cotoneaster acutifolia		
Intercept	79.190	3.650	6.700
Slope	-0.110	-0.006	-0.009
	Juniperus sabina		
Intercept	93.240	5.900	6.070
Slope	-0.099	-0.008	-0.010

-- Data not recorded.

than on root development (Dinter and Eaton 1976; McGuire and Bunce 1970; Ticknor 1980).

Furthermore, these results suggest that there is "a certain critical level" of soluble salts in the rooting medium that each species is able to tolerate and thus able to initiate rooting and root development by taking advantage of the mineral nutrients present in the fertilized rooting medium. Similar to data reported by Hamilton and Johnson (1978) and those obtained under the conditions of the present experiment (Figs. 3, 4, 5, 6 and 7), levels of soluble salts (100 to 500 µmhos/cm) were far below the "critical point of 4,000 µmhos/cm" indicated by Dinter and Eaton (1976). These lower levels of soluble salts are noteworthy; considering that soluble salts were determined in an aquous extract of the rooting medium (section 3.1.3.2), the greater retention of mineral salts by peat moss in the rooting medium (Hamilton and Johnson 1978; Prasad and Woods 1971) may have resulted in lower levels of soluble salts in the extract than those actually existing in the rooting medium. Besides that, the 4,000 µmhos/cm critical level is an arbitrary limit that adversely affects the growth of a wide range of common agricultural plants and applies almost exclusively to soils (Hausenbuiller 1978); a similar value for artificial mixtures is not universally known.

According to results obtained in the present experiments (Figs. 3, 4, 5, 6 and 7) and data reported by Chong (1982b) and by Hamilton and Johnson (1978), the critical level of soluble salts in the medium for normal rooting of cuttings appears to be much lower than the critical tolerable level for whole plants. Hathaway (1976) and Reavis et al. (1980) have reported inhibitory effect of levels of soluble salts which were lower than 4,000 μmhos/cm on seed germination and growth of newly formed roots. Furthermore, considering that the highest level of soluble salts obtained by Dinter and Eaton (1976) was 1,020 μmhos/cm, and that rooting was reduced in most species studied, it may be concluded that the "critical level" for cuttings of those species studied by Dinter and Eaton were less than 1,020 μmhos/cm.

Since whole plants vary in their tolerance to levels of soluble salts, it is expected that cuttings also would have this variability. An attempt was made to establish a range of soluble salts in the rooting medium which probably contains the "critical level" for cuttings of the species studied in the present experiments. The highest level of soluble salts for the Osmocote treatment that did not significantly reduce the rooting parameters (rooting percentage, root length and root number) as compared to the untreated control was considered the lower limit of the soluble salts range containing the critical level. Conversely, the upper limit was determined by the lowest level of

soluble salts for the corresponding Osmocote treatment that reduced rooting percentage, root length and root number significantly.

Interestingly, the suggested critical levels plotted against the slope of the corresponding regression curve between rooting parameters and soluble salts in the medium for the species studied appears to show a logarithmic relationship of the type 'log critical level = B_o - B_1 log slope' in the case of rooting percentage and root length (Figs. 11 and 12, respectively). Root number less accurately reflected this type of relationship. No mathematical relationship was found between the suggested critical levels and the intercepts of the regression curves (rooting parameters versus soluble salts in the rooting medium). However, further studies with a wider range of species in different rooting media are necessary to prove this relationship.

5.3 Mineral Nutrients

Levels of soluble salts from Osmocote 14-14-14 (Fig. 3) and from Osmocote 19-6-12 (Fig. 4) both of the 3- to 4-month release formulation, showed similar increasing trends with increasing rates. Osmocote 19-6-12 gave consistently higher soluble salts readings at each rate. With K content approximately the same in both formulations, and assuming that most of the P

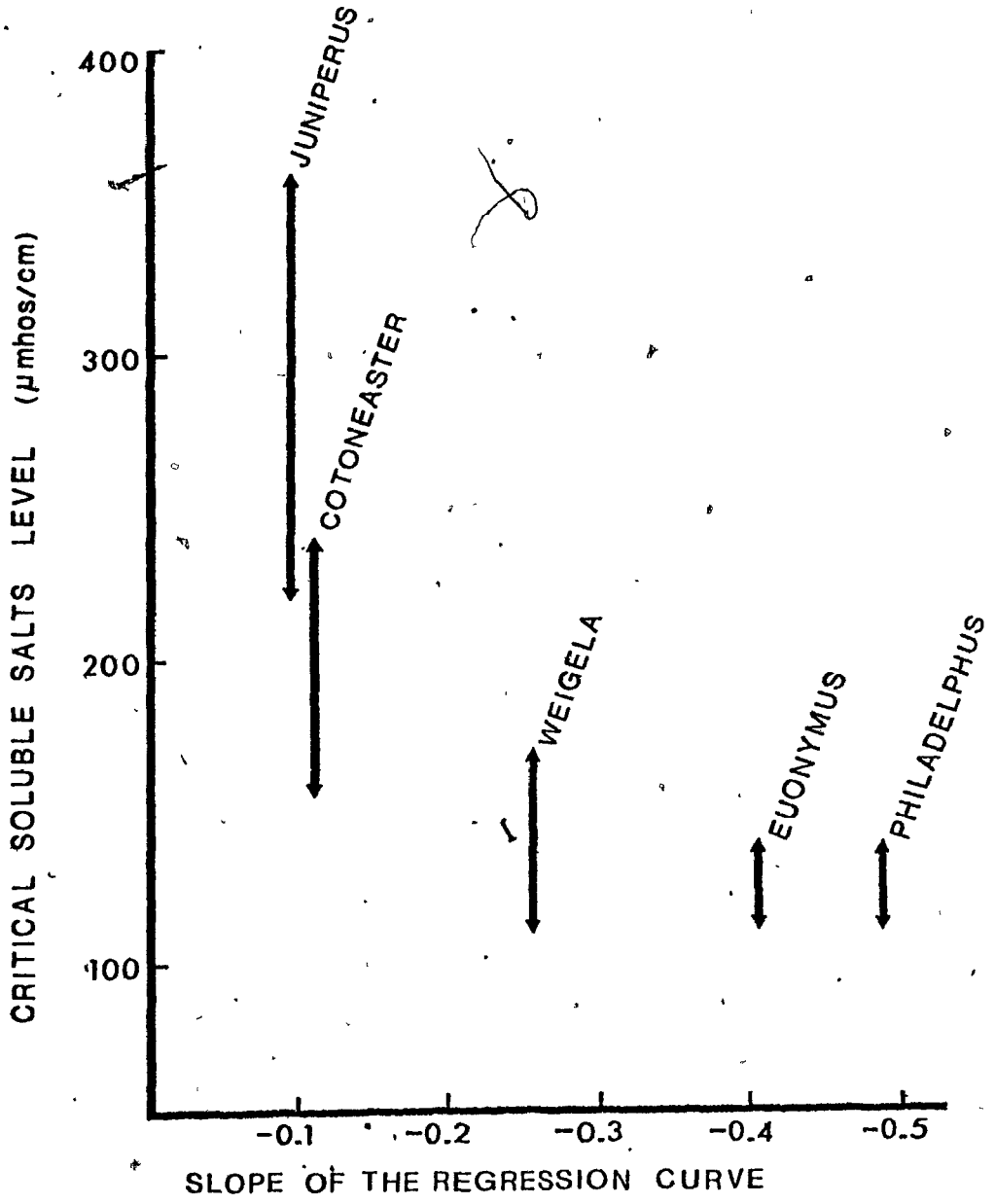


Fig. 11. Relationship of the critical soluble salts levels of cuttings with the slope of the regression curve between rooting percentage and soluble salts.

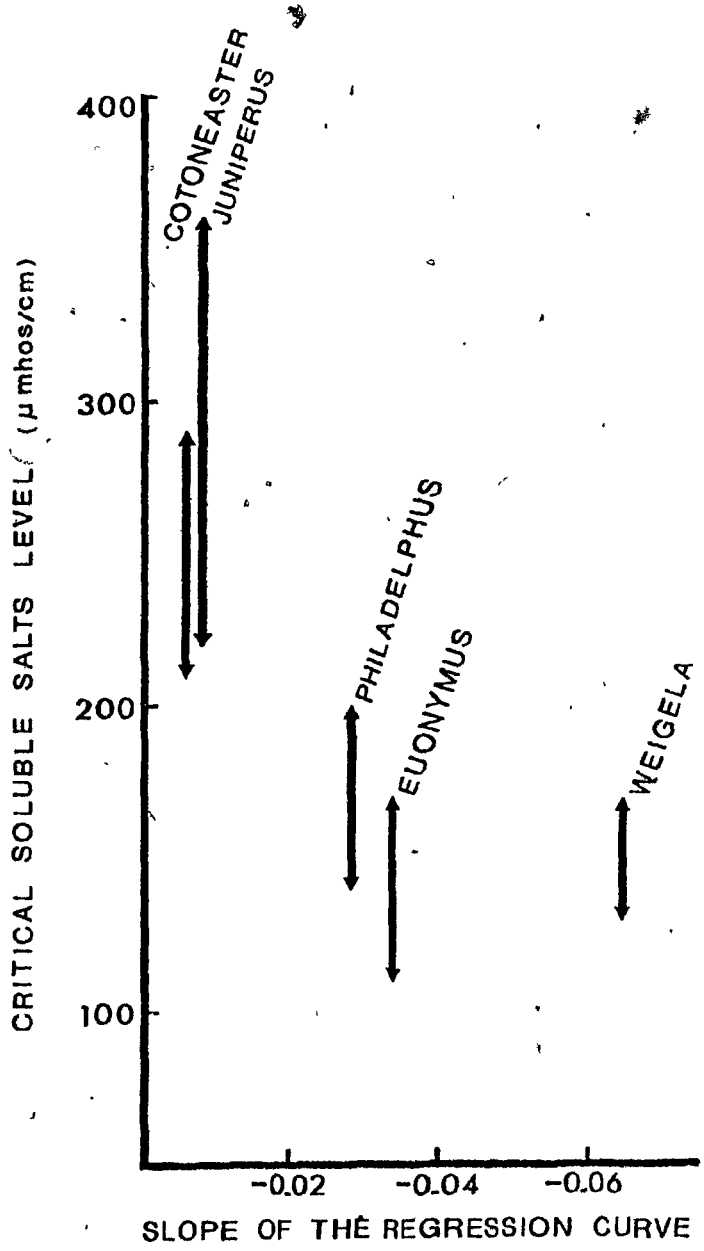


Fig. 12. Relationship of the critical soluble salts levels of cuttings with the slope of the regression curve between root length and soluble salts.

was retained in the medium (Cochrane and Matkin 1966), N seemed to be predominantly responsible for the differentially higher levels of soluble salts obtained with Osmocote 19-6-12 formulation (19% N versus 14% N according to manufacturer's specifications). Conditions were similar in both cases, except for a slightly higher average temperatures during the experiment with Osmocote 14-14-14 (Appendix Figs. 1 and 2). External accumulated soluble salts did not influence the release rate of Osmocote (Oertli and Lunt 1962a). These results agree with data presented by Johnson et al. (1981) showing similar trends of soluble salts and of NO_3^- at different Osmocote rates and in different media. Furthermore, of the leaching curves of NO_3^-, P and K presented by Cochrane and Matkin (1966) and by Hamilton and Johnson (1978), the NO_3^- releasing curve presented the closest similarity to the soluble salts curves obtained in the present experiments (Figs. 5, 6 and 7). However, Lunt et al. (1961) and Oertli and Lunt (1962b) reported similar releasing curves for N, P and K, although N release was faster and higher than P and K released under similar conditions. Different rates of Osmocote did not alter the pattern of the N releasing curve (Patel and Sharma 1977).

The hydrolitic ratio of 1:10 medium:water used in soluble salts determination (section 3.1.3.2) may have influenced aqueous extract composition to some extent. Thus, chloride and NO_3^-

concentrations in the rooting medium are expected to be slightly higher than the values normally found for the specific conductivity readings obtained with higher ratios of dilution because these anions decrease more than proportionately by dilution of the suspension (Jackson 1958).

Considering that soluble salts represent mainly NO_3^- released by Osmocote, the higher levels of soluble salts obtained with surface application (Figs. 3, 4, 6 and 7) seemed to contradict results reported by Lunt and Oertli (1962) in which incorporated methods resulted in significantly higher leaching of N from the medium than surface application. However, they concluded that it was due to the intermittent drying in the case of surface-applied Osmocote. For the experiment presented herein, surface-applied Osmocote was kept continuously wet with the misting system used (section 3.1.1). Similar results were obtained for P and K (Oertli and Lunt 1962a).

The differences between the initial mineral content of cuttings and that of the control (no fertilizer added) at the end of each experiment (Tables 5, 6, 7, 16 and 25) corroborated data presented by Sharpe (1955) suggesting a leaching effect of the elements analyzed. However, the fact that those differences were higher in the case of softwood cuttings of deciduous species (Tables 5, 6 and 7) as compared to hardwood cuttings of

the evergreen species (Table 16) suggests that softwood cuttings increased in dry weight during the rooting period due to additions of carbohydrates from photosynthesis (Good and Tukey 1965).

Of the four elements analyzed (N, P, K and Ca), only K content showed significant decreases in time after the first harvest date (Tables 16 and 24) indicating a greater leaching of this element in Cotoneaster and Juniperus. These results corroborate data reported by various researchers (Good and Tukey 1965; Sharpe 1955; Sorensen and Coorts 1968; Wott and Tukey 1965). However, all elements analyzed in Euonymus, Philadelphus and Weigela showed similar decreases (Tables 5, 6 and 7). It is possible that this may be due to dry weight increase in the cuttings during the rooting period and not to actual leaching of these elements (Good and Tukey 1964). Ca content did not vary during the rooting period of Juniperus sabina (Table 16). Since Ca is considered a difficult-to-leach element (Good and Tukey 1967; Mecklenburg et al. 1966; Sharpe 1955) and was not added to the rooting medium, it can be concluded that this species most likely did not change in dry weight during rooting, although dry weight at the beginning of the experiment was not recorded.

Raviv and Regev (1980) found that leaching from chrysanthemum cuttings was inhibited somewhat by the presence of Osmocote in the rooting medium. However, in the experiments reported

herein, except in Juniperus, none of the Osmocote treatments studied was able to replenish the losses due to leaching and/or dilution (Tables 5, 6, 7 and 24). In comparison with N and P contents, K content was not influenced by Osmocote rate in Juniperus sabina cuttings (Table 16). On the other hand, K content was reduced in time after the first harvest date (Table 16), indicating that leaching losses were higher than possible K supply with the use of Osmocote.

Increasing rates of Osmocote affected differently N, P and K contents of cuttings depending on species (Tables 5, 6, 7, 16 and 24). Johnson and Hamilton (1977) obtained higher N, P and K contents in Juniperus conferta and Ligustrum japonicum cuttings with increasing rates of surface-applied Osmocote 14-14-14 (0 to 0.2 kg/m^2) and also of surface-applied Osmocote 18-6-12 (0 to 0.16 kg/m^2). Similarly, Ward and Whitcomb (1976) found increases of N, P and K contents in Ilex crenata 'Hetzi' cuttings two months after sticking in medium treated with surface-applied Osmocote 18-6-12 as compared to untreated medium; at this time 100% rooting had been obtained in all the cases. Generally, in the present study, the highest rates of surface-applied Osmocote resulted in significant increases of N, P and K contents of cuttings (Tables 5, 6, 7 and 24), and also the highest rates of incorporated Osmocote in the case of Juniperus (Table 16). However, inconsistent correlations were observed

between soluble salts (reflecting fertilizer salts released from Osmocote treatments) and mineral contents of cuttings (reflecting possible absorption of fertilizer from the rooting medium) (Tables 11, 15, 19 and 27). This appears to be contradictory since these Osmocote treatments reduced all rooting parameters studied, and therefore fewer and smaller roots were present in the rooting medium to absorb the mineral elements released from the Osmocote, producing the increases indicated above. Furthermore, Wott and Tukey (1969) observed that chrysanthemum cuttings absorbed only small quantities of P even though P was plentiful in the rooting medium. They stated that their results could be applied to a wide range of plants and nutrients. Narrow-leaved evergreens propagated as hardwood cuttings absorbed only small quantities of nutrients during propagation (Wott and Tukey 1967). More investigation is necessary to elucidate this problem, probably by monitoring mineral contents in the rooting medium and in cuttings at frequent intervals after sticking, since mineral contents of tissues follow more closely the contents in the medium than the rate of fertilizer applied, except for N (Jones 1974).

Since tissue samples were composed of leaves with or without other above-ground part of cuttings, one possible explanation may be the translocation of those elements from top to roots after root initiation occurred. Good and Tukey (1965,

1967) working with chrysanthemum reported that while N translocation was variable during the rooting period, P translocated to both new leaves and roots and K only to new leaves. Ca was immobile during the rooting period. The unchanging contents of Ca obtained in all experiments (Tables 5, 6, 7, 16 and 24) confirm the immobility of this element (Good and Tukey 1967). Blazich and Wright (1979) observed no translocation of nutrients from the upper portions to the bases of Ilex crenata cuttings.

Considering 2-4.5% N, 0.2-0.6% P and 1.5-3.5% K as optimum nutrient contents of leaves (Smith 1978), some deficiencies were possibly present but not visually obvious at the end of the experiments, especially for P and K in all species studied, but not for P in Weigela (Table 7). Juniperus (Table 16) was not considered since above-ground parts were taken for analysis, giving lower nutrient contents than leaves alone (Haun and Cornell 1951; Kelley and Shier 1965) and evergreens usually have lower mineral contents than deciduous species (Smith 1973). According to Swanson and Davis (1977), P deficiency caused reduced rooting, and K deficiency did not influence rooting adversely. However, differences among species and seasonal changes in nutrient contents of leaves normally occur (Cannon et al. 1960; Davidson 1960; Kelley and Shier 1965) making it difficult to establish reliable ranges under artificial conditions such as in mist propagation (Jones 1974).

Consistent negative correlations of all elements analyzed with rooting performance was obtained only for Euonymus, Philadelphus and Weigela cuttings (Table 8). While N has been negatively related to root initiation (Basu and Ghosh 1974; Haun and Cornell 1951; Pearse 1943; Starring 1923; Swanson and Davis 1977; Wott and Tukey 1967), P and Ca have been positively related (Graca and Hamilton 1981a; Kramer 1969; Swanson and Davis 1977). Interestingly, in comparison with initial contents, the above three species showed the largest final decreases in N, P, K and Ca contents due mainly to increases in dry weight, as assumed above. Perhaps the significant correlations obtained (Table 8) resulted from a parallelism between the rooting process and the top growth process, the latter inducing dilution of the elements analyzed.

The consistent negative correlation between K content and rooting performance of cuttings of all species studied (Tables 8, 13, 17 and 25) is noteworthy. Although K is considered independent of the rooting process (Preston et al. 1953; Swanson and Davis 1977), Sorensen and Coorts (1968) also obtained negative correlations between K content and rooting of Buxus sempervirens, Ilex crenata microphylla, Juniperus horizontalis plumosa and Taxus media cuttings similar to those presented in the Tables indicated above. Considering the diversity of species involved, these results appear sufficient to account for

a role of K in the rooting process, although a satisfactory explanation is not known. Perhaps K is involved in one or more enzymatic processes during rooting and/or root growth (Swanson and Davis 1977), or it is influencing quality and quantity of carbohydrates present in cutting tissues (Liebhardt 1968). Further fundamental investigation is necessary to prove this relationship.

5.4 pH

The rooting performance of cuttings in relation with the pH of the medium was somewhat less consistent than with levels of soluble salts (Tables 10, 15, 19 and 27). This is in agreement with data reported by various researchers (Albert 1975; Hitchcock 1926; Raabe and Vlamis 1966) indicating that the low pH of peat moss generally is not a limiting factor for rooting. Smith (1926) reported that pH range from 7.0 to 7.2 was most favorable for rooting of Coleus blumei.

With soil, an increase in pH with dilution from the "sticky point" (Jackson 1958) to a ratio of 1:10 (similar to that used in the present experiments, section 3.1.3.2) is usually in the order of 0.2 to 0.5 pH unit. Although the actual values for the pH of the rooting medium in these experiments might be expected to be slightly lower because of dilution, the magnitude

of this difference is not known (Jackson 1958).

The pH of the rooting medium was reduced with the presence of Osmocote either incorporated or surface-applied as compared to the control from 5.3 to 4.6 for the highest rates at the end of each experiment (Tables 9, 14, 18 and 26). This agrees with results obtained by Dinter and Eaton (1976). However, different rates of Osmocote surface-applied did not influence the pH of the rooting medium (Tables 9, 14 and 26) corroborating data reported by Hamilton and Johnson (1978) with surface-applied Osmocote in two different rooting media. Simpson et al. (1975) reported a substantial decrease of pH with surface-applied Osmocote versus incorporated Osmocote.

On the other hand, the initial pH of the rooting medium (pH 4.3) was increased in time more with decreasing rates of Osmocote (Tables 18 and 26). Somewhat similar trends were obtained by Chong (1982b), although he used a different rooting medium.

The significant negative correlation of pH and soluble salts in the rooting medium (sections 4.1.3; 4.2.2; 4.3.3; and 4.4.3) could be a result of a junction potential at the calomel electrode, or the suppression of the diffuse ion layer around the colloid in suspension (Black 1964). Since mineral nutrients re-

leased from Osmocote are not affected by pH of the medium (Oertli and Lunt 1962a, 1962b), the variation of pH indicated above did not account for the differences in soluble salts obtained in all experiments (Figs. 3, 4, 5, 6 and 7).

Although pH of the medium is an important factor in nutrient absorption by roots (Bassioni 1971; Munn and Jackson 1978) the relationships between pH of the rooting medium and mineral contents of cuttings were inconsistent (Tables 11, 15, 19 and 27).

As shown by the evidence of these experiments there appeared to be some obvious relationships between speed of rooting and effect of Osmocote, although this point needs further clarification. IBA treatments that allowed cuttings to remain for longer periods in the propagation bench seemed to be of benefit when controlled-release fertilizers were added to the rooting medium. An important factor of consideration when dealing with fertilizers applied to the medium is the type and composition of the rooting medium which seems to determine the maximum safe dose of controlled-release fertilizer and maintain levels of soluble salts in ranges compatible with the species being propagated.

6. SUMMARY

Research has indicated that Osmocote in the rooting medium influenced rooting performance and subsequent growth of cuttings. The objective of these experiments was to investigate the effects of controlled-release fertilizers in the rooting medium on the ability to root, on the tolerance of cuttings of different species to soluble salts levels of the medium and on the mineral nutrient composition of cuttings.

Stem cuttings of Euonymus alata, Philadelphus coronarius 'Aureus', Weigela 'Bristol Ruby', Cotoneaster acutifolia and Juniperus sabina were rooted in outdoor (during the growing season) or indoor (under greenhouse conditions) frames provided with intermittent mist. The rooting medium was 1:1 (v/v) peat moss and perlite treated with different rates (0 to 0.6 kg/m^2 surface-applied and/or 0 to 4.0 kg/m^3 incorporated) of Osmocote 14-14-14 (3- to 4-month release), Osmocote 19-6-12 (3- to 4-month release) or Osmocote 18-6-12 (8- to 9-month release). Treatment of Cotoneaster cuttings with indolebutyric acid (IBA) was also investigated in conjunction with Osmocote treatments. Rooting performance (rooting percentage, root length and root number) and mineral nutrient contents (N, P, K and Ca) of cuttings, as well as soluble salts and pH of the rooting medium were compared among Osmocote treatments.

Cotoneaster cuttings treated with 0.3% IBA in powder form rooted better in Osmocote medium at rates of 0.15 kg/m^2 surface-applied and 1.0 kg/m^3 incorporated, than in control medium without Osmocote. Similar cuttings treated with 5,000 and 20,000 ppm IBA in liquid form rooted poorer in Osmocote treated medium, with rates between 0.15 and 0.60 kg/m^2 surface-applied and between 1.0 and 4.0 kg/m^3 incorporated, in comparison with control medium without Osmocote.

Incorporation of Osmocote gave consistently better rooting of cuttings than surface-applied Osmocote. Osmocote formulations of longer release period (8- to 9-month release) appeared better suited for adding to rooting medium than faster-release formulations (3- to 4-month release) from the stand point of rooting of cuttings.

Increasing rates of Osmocote consistently increased the levels of soluble salts in the rooting medium. Although an increasing trend of pH of the rooting medium in time was observed, the presence of Osmocote seemed to reduce the pH in comparison with the untreated control from 5.3 to 4.6. However, these differences in pH did not seem to account for the observed differences in rooting performance.

Juniperus and Cotoneaster appeared to be more tolerant to

soluble salts than Euonymus, Philadelphus and Weigela. An inverse relationship between rooting performance of cuttings and levels of soluble salts in the rooting medium was obtained. A suggested model relating critical levels of soluble salts with slopes of the regression curves between rooting performance and soluble salts in the rooting medium appeared to be of logarithmic type for rooting percentage and root length.

Although N, P and K contents of cuttings were increased in some instances by increasing rates of surface-applied Osmocote, mineral nutrients did not seem to be absorbed in appreciable quantities by rooting cuttings and none of the Osmocote rates studied were able to replenish the mineral losses due to leaching of cutting tissues. Ca content remained unchanged with different Osmocote treatments. K content was negatively correlated to rooting performance for all species studied suggesting a role for K in the rooting process.

The rooting medium composition seemed to be an important factor when controlled-release fertilizers are added to maintain soluble salts in levels compatible with the species being propagated. The influence of controlled-release fertilizers in the rooting medium must be determined empirically for each species or cultivar under particular rooting circumstances.

7. SUGGESTIONS FOR FUTURE RESEARCH

1. Further experiments with a wider range of species and with a variety of media should yield data which can be used to construct a more precise model to predict rooting performance in relationship with Osmocote rate, and thus determine the critical levels of species to soluble salts in the rooting media.

2. The consistent negative correlation between K content and rooting performance of cuttings of all species reported in the present experiments are indicative of a possible role of K in rooting of cuttings. Further investigations of the role of K in the rooting process such as its possible relationship with rooting substances (i.e. hormones, cofactors, enzymes, inhibitors) or with carbohydrates should help to clarify this point.

3. There appears to be some obvious relationships between speed of rooting (and factors that affect it, such as IBA treatments) and influence of Osmocote in the rooting medium. These relationships need further clarification.

4. Since the role of mineral nutrient contents alone did not satisfactorily explain differences in rooting performance of

cuttings when Osmocote was present in the rooting medium, future investigation should consider the role of carbohydrates in the rooting process in relationship with dry weight increase or decrease and mineral contents of cuttings rooted in fertilized medium.

8. LITERATURE CITED

Albert, L. S. 1975. Physiology of roots. Proc. Int. Plant Prop. Soc. 25: 392-399.

Association of Official Analytical Chemists. 1975. Official methods of analysis, 12th ed. A.O.A.C. Washington, DC 20044.

Bachelard, E. P., and B. B. Stowe. 1962. A possible link between root initiation and anthocyanin formation. Nature 194: 209-210.

Baker, J. H., and T. Greweling. 1967. Extraction procedure for quantitative determination of six elements in plant tissue. J. Agr. Food Chem. 15: 340-344.

Barr, C. E., and A. Ulrich. 1963. Phosphorus fractions in high and low phosphate plants. J. Agr. Food Chem. 11: 313-316.

Barron, H. M. 1974. The use of slow-release fertilizers. Proc. Int. Plant Prop. Soc. 24: 221-229.

Bassioni, N. H. 1971. Temperature and pH interaction in NO_3 uptake. Plant and Soil 35: 445-448.

Basu, R. N., and S. K. Ghosh. 1974. Effect of nitrogen nutrition of stock plants of Justicia gendarussa L. on the rooting of cuttings. J. Hort. Sci. 49: 245-252.

Bhan, K. C., A. Wallace, and O. R. Lunt. 1959. Some mineral losses from leaves by leaching. Proc. Amer. Soc. Hort. Sci. 73: 289-293.

Bindra, A. S. 1976. Effect of Fe-EDDHA on rhizogenesis and success of transplanting in peach almond hybrid plants. Soil and Culture 42: 157-158.

Biron, I., and A. H. Halevy. 1973. The relationship between rooting of dahlia cuttings and the presence and type of bud. Physiol. Plant. 28: 244-247.

Black, C. A. 1964. Soil-plant relationships. John Wiley and Sons, Inc. N. Y.

Blazich, F. A., and R. D. Wright. 1979. Non-mobilization of nutrients during rooting of Ilex crenata Thumb. cv. Convexa stem cuttings. HortScience 14: 242.

Bouillenne, R., and M. Bouillenne-Walrand. 1955. Auxines et bouturage. Rpt. 14th. Int. Hort. Cong. Vol I: 231-238.

Brown, B. F., and M. A. Dirr. 1976. Cutting propagation of selected flowering crabapple types. Plant Prop. 22: 4-5.

Bukovac, M. J., and S. H. Wittwer. 1957. Absorption and mobility of foliar applied nutrients. Plant Physiol. 32: 428-435.

Burrows, W. J., and D. J. Carr. 1969. Effect of flooding the root system of sunflower plants on the cytokinin content in xylem sap. Physiol. Plant. 22: 1105.

Cannon, T. F., L. C. Chadwick, and K. W. Reisch. 1960. The nutrient element status of some ornamental trees. Proc. Amer. Soc. Hort. Sci. 76: 661-666.

Carney, M., and C. E. Whitcomb. 1980. Effects of slow-release sources of nitrogen and potassium on the propagation and subsequent growth of Ilex crenata 'Hetzi', Pyracantha coccinea 'Wateri', and Rhododendron x 'Fashion'. Okl. Agr. Expt. Sta. Res. Rpt. P-803: 46-48.

Carney, M., and C. E. Whitcomb. 1981. Effects of slow-release sources of nitrogen and potassium on the propagation and subsequent growth of Ilex crenata 'Hetzi', Pyracantha coccinea 'Wateri', and Rhododendron x 'Fashion'. Okl. Agr. Expt. Sta. Res. Rpt. P-818: 19-20.

Chong, C. 1981. Influence of high IBA concentration on rooting. Proc. Int. Plant Prop. Soc. (in press).

Chong, C. 1982a. High IBA concentration stimulates rooting in woody species. Nursery Trades B.C. 1: 28-29.

Chong, C. 1982b. Rooting response of two Cotoneaster species to surface-applied Osmocote slow-release fertilizer. Plant Prop. (in press).

Chong, C. 1982c. Influence of Ethephon on rooting. Amer. Nurseryman (in press).

Cochrane, R. C., and O. A. Matkin. 1966. Nutrient supply characteristics of slow-release fertilizers. Plant Prop. 12: 2-10.

Coleman, R. A., T. Mock, and T. Furuta. 1978. Effectiveness of Osmocote fertilizer influenced by placement and dosage. Calif. Agr. 32: 12-13.

Cooper, W. C. 1935. Hormones in relation to root formation on stem cuttings. Plant Physiol. 10: 789-794.

Coorts, G. D. 1969. The effect of minor element deficiency on rooting of woody ornamentals. Plant Prop. 15: 15-16.

Coorts, G. D., and C. C. Sorensen. 1968. Organisms found growing under nutrient mist propagation. HortScience 3: 189-190.

Davidson, H. 1960. Nutrient element composition of leaves from selected species of woody ornamental plants. Proc. Amer. Soc. Hort. Sci. 76: 667-672.

Deen, J. L. W. 1973. Nutrition of cuttings under mist. Proc. Int. Plant Prop. Soc. 23: 137-141.

Dinter, B. J. F., and G. W. Eaton. 1976. Effect of nutrients in the rooting medium on the rooting ability of cuttings. Plant Prop. 22: 10-13.

Diver, S., and C. E. Whitcomb. 1981. The effects of dolomite, micromax and propagation media on the rooting and subsequent growth of Pyracantha coccinea and Juniperus procumbens. Okl. Agr. Expt. Sta. Res. Rpt. P-818: 21-23.

Doak, B. W. 1940. The effect of various nitrogenous compounds on the rooting of Rhododendron cuttings treated with α-naphthalene-acetic acid. N. Z. J. Sci. Tech. 21: 336A-343A.

Doran, W. L. 1957. Propagation of woody plants by cuttings. Univ. Mass. Expt. Sta. Bull. 491.

Eck, P., and A. W. Stretch. 1979. Cutting wood production from highbush blueberry mother block plants as affected by nitrogen nutrition and fungicide treatment. HortScience 14: 599-600.

Ericksen, E. N. 1974. Root formation in pea cuttings. III: The influence of cytokinin at different developmental stages. Physiol. Plant. 30: 163-167.

Evans. H. 1951. Investigations on the propagation of cacao. Tropical Agric. 28: 147-203.

Fadl, M. S., and H. T. Hartmann. 1967. Relationship between seasonal changes in endogenous promoters and inhibitors in pear buds and cutting bases and the rooting of the hardwood cuttings. Proc. Amer. Soc. Hort. Sci. 91: 96-112.

Fisher, G. M. 1943. Conifer propagation with mist. Amer. Nurseryman 77: 9-10.

Fox, B. S. 1972. Propagation of cotoneasters. Proc. Int. Plant Prop. Soc. 22: 213-219.

Gibson, J., A. Storjohann, and C. E. Whitcomb. 1977. A comparison of three Osmocote formulations and two rooting and growing media on liner quality. Okl. Agr. Expt. Sta. Res. Rpt. P-760: 54-56.

Gilliam, C. H., T. A. Fretz, and W. J. Sheppard. 1980. Effect of nitrogen form and rate on elemental content and growth of Pyracantha, Cotoneaster and Weigela. Scientia Hort. 13: 173-179.

Glenn, R., C. Hogan, and C. E. Whitcomb. 1975. Effects of Osmocote in the rooting medium and auxin levels on rooting and subsequent growth of cuttings. Okl. Agr. Expt. Sta. Res. Rpt. P-724: 43-45.

Good, G. L., and H. B. Tukey, Jr. 1964. Leaching of nutrients from cuttings under mist. Proc. Int. Plant Prop. Soc. 14: 138-142.

Good, G. L., and H. B. Tukey, Jr. 1965. The influence of intermittent mist on the mineral nutrient content of cuttings during propagation. Proc. Int. Plant Prop. Soc. 15: 78-86.

Good, G. L., and H. B. Tukey, Jr. 1966. Leaching of metabolites from cuttings propagated under intermittent mist. Proc. Amer. Soc. Hort. Sci. 89: 727-733.

Good, G. L., and H. B. Tukey, Jr. 1967. Redistribution of mineral nutrients in Chrysanthemum morifolium during propagation. Proc. Amer. Soc. Hort. Sci. 90: 384-388.

Gorter, C. J. 1958. Synergism of indole and indole-3-acetic acid in the root production of Phaseolus cuttings. Physiol. Plant. 11: 1-9.

Gorter, C. J. 1969. Auxin-synergists in the rooting of cuttings. Physiol. Plant. 22: 497-502.

Gouin, F. R. 1974. Osmocote in the propagation house. Proc. Int. Plant Prop. Soc. 24: 337-341.

Graca, M. E. C., and D. F. Hamilton. 1981a. Effects of nitrogen and phosphorus on root and shoot growth of Cotoneaster divaricata Rehd. & Wils. Scientia Hort. 15: 77-85.

Graca, M. E. C., and D. F. Hamilton. 1981b. Effects of controlled-release fertilizer on root and shoot growth of Cotoneaster divaricata Rehd. & Wils. Scientia Hort. 15: 87-91.

Greweling, T. 1962. An extraction procedure for the determination of total calcium, magnesium and potassium in plant tissue. J. Agr. Food Chem. 10: 138-140.

Greweling, T. 1966. The chemical analysis of plant tissue. Cornell Univ. Agron. mimeo 6620.

Haissig, B. E. 1972. Meristematic activity during adventitious root primordium development. Influences of endogenous auxin and applied gibberellic acid. Plant Physiol. 49: 886-892.

Hall, I. V., and L. E. Aalders. 1970. Rooting lowbush blueberry cuttings under nutrient mist. Canada Agr. 15: 16.

Hamilton, D. F., and C. R. Johnson. 1978. Effects of organic matter and controlled-release fertilizer on nutrient retention during intermittent-mist propagation. Scientia Hort. 8: 155-162.

Hartmann, H. T., and D. E. Kester. 1975. Plant Propagation. Principles and practices, 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, N. J.

Hathaway, R. D. 1976. Effects of slow-release fertilizer on the germination of tree seed. Okl. Agr. Expt. Sta. Res. Rpt. P-741: 39-40.

Haun, J. R., and P. W. Cornell. 1951. Rooting response of geranium (Pelargonium hortorum Bailey var. Ricard) cuttings as influenced by nitrogen, phosphorus, and potassium nutrition of the stock plant. Proc. Amer. Soc. Hort. Sci. 58: 317-323.

Hausenbuiller, R. L. 1978. Soil Science. Principles and practices, 2nd ed. Wn. C. Brown Co. Pub. Iowa.

Henderson, S., and C. E. Whitcomb. 1980. The effect of rate and time of application of three micronutrient sources on production of Juniperus procumbens, Ilex crenata 'Hetzi' and Catharansus rosea 'Little Bright Eye Periwinkle'. Okl. Agr. Expt. Sta. Res. Rpt. P-803: 55-56.

Hess, C. E. 1962. A physiological analysis of root initiation in easy and difficult-to-root cuttings. XVIth Int. Hort. Cong. 1962: 375-381.

Hess, C. E. 1965a. Mist from a cutting's viewpoint. Proc. Int. Plant Prop. Soc. 15: 71-73.

Hess, C. E. 1965b. Rooting co-factors. Identification and function. Proc. Int. Plant Prop. Soc. 15: 181-186.

Hess, C. E., and W. E. Snyder. 1955. A physiological comparison of the use of mist with other propagation procedures used in rooting cuttings. XIVth Int. Hort. Cong. 1955: 1133-1139.

Hitchcock, A. E. 1928. Effect of peat moss and sand on rooting response of cuttings. Bot. Gaz. 86: 121-148.

Hitchcock, A. E., and P. W. Zimmerman. 1926. Variation in rooting response of cuttings placed in media in different pH value. Proc. Amer. Soc. Hort. Sci. 23: 383-389.

Hoeven, A. P. Van Der, and C. P. Mol. 1979. Osmocote appears to be worthwhile in the rooting of chrysanthemum cuttings (in Dutch) (Abstr.). Vakblad voor de Bloemisterij 34: 32-33.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, N. J.

Jain, R. K., V. K. Garg, and S. D. Khanduja. 1981. Macronutrient element composition of leaves from some ornamental shrubs grown on normal and alkali soils. J. Hort. Sci. 56: 169-171.

Johnson, C. R., and D. F. Hamilton. 1977. Effects of media and controlled-release fertilizers on rooting and leaf nutrient composition of Juniperus conferta and Ligustrum japonicum cuttings. J. Amer. Soc. Hort. Sci. 102: 320-322.

Johnson, C. R., J. T. Midcap, and D. F. Hamilton. 1981. Evaluation of potting-media, fertilizer source and rate of application on chemical composition and growth of Ligustrum japonicum Thumb. Scientia Hort. 14: 157-163.

Jones, J. B. 1974. Plant analysis handbook for Georgia. Coop. Ext. Serv. Univ. Georgia, College of Agr. Bull. 735.

Kamp, J. R., and C. R. Bluhm. 1950. Effect of nutrients on the rooting responses of softwood cuttings. Proc. Amer. Soc. Hort. Sci. 56: 482-484.

Kawase, M. 1972. Effect of flooding on ethylene concentrations in horticultural plants. J. Amer. Soc. Hort. Sci. 97: 584-586.

Keever, G. J., and H. B. Tukey, Jr. 1979. Effect of intermittent nutrient mist on the propagation of azaleas. HortScience 14: 755-756.

Kelley, J. D., and R. W. Shier. 1965. Seasonal changes in the macronutrient composition of leaves and stems of Taxus media. Proc. Amer. Soc. Hort. Sci. 86: 809-814.

Kramer, P. J. 1969. Plant and soil water relationships. A modern synthesis. McGraw Hill Co. N. Y.

Lee, C. I., J. L. Paul, and W. P. Hackett. 1976. Effect of Ca saturation and air filled porosity of sphagnum peat on root regeneration of Pistacia chinensis Bunge and Liquidambar styraciflua L. J. Amer. Soc. Hort. Sci. 101: 233-236.

Lee, C. I., and H. B. Tukey, Jr. 1971a. Induction of root-promoting substances in Euonymus alatus 'Compactus' by intermittent mist. J. Amer. Soc. Hort. Sci. 96: 731-736.

Lee, C. I., and H. B. Tukey, Jr. 1971b. Development of root-promoting substances in Euonymus alatus 'Compactus' under intermittent mist. Proc. Int. Plant Prop. Soc. 21: 343-349.

Liebhardt, W. C. 1968. Effect of potassium on carbohydrate metabolism and translocation. In: The role of potassium in Agriculture. Edited by V. J. Kilmer, S. E. Younts, and N. C. Brady. Wisconsin. pp 147-164.

Loach, K. 1979. Mist propagation - past, present and future. Proc. Int. Plant Prop. Soc. 29: 216-229.

Long, J. C. 1932. The influence of rooting media on the character of roots produced by cuttings. Proc. Amer. Soc. Hort. Sci. 29: 352-355.

Lunt, O. R., A. M. Kofranek, and J. J. Oertli. 1961. Controlled availability fertilizers. Coated fertilizers. Calif. Agr. 15: 2.

Lunt, O. R., and J. J. Oertli. 1962. Controlled-release of fertilizer minerals by incapsulating membranes. II Efficiency of recovery, influence of soil moisture, mode of application, and other considerations related to use. Soil Sci. Soc. Amer. Proc. 26: 584-587.

Mann, C. E. T., and T. Wallace. 1925. The effects of leaching with cold water on the foliage of the apple. J. Pom. Hort. Sci. 4: 146-161.

Matkin, O. A. 1970. Use of soil analysis in Osmocote fertilizer programs. HortScience 5: 180-181.

Maynard, D. N., and O. A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. Hort. Revs. 1: 79-140.

McGuire, J. J., and V. J. Bunce. 1970. Use of slow-release fertilizers in a propagating medium. Plant Prop. 16: 10-14.

Mecklenburg, R. A., and H. B. Tukey, Jr. 1964. Influence of foliar leaching on root uptake and translocation fo calcium-45 to the stems and foliage of Phaseolus vulgaris. Plant Physiol. 39: 533-536.

Mecklenburg, R. A., H. B. Tukey, Jr., and J. V. Morgan. 1966. A mechanism for the leaching of calcium from foliage. Plant Physiol. 41: 610-613.

Meyer, M. M., Jr., and H. B. Tukey, Jr. 1965. Nitrogen, phosphorus, and potassium plant reserves and the spring growth of Taxus and Forsythia. Proc. Amer. Soc. Hort. Sci. 87: 537-544.

Morgan, J. V. 1963. The occurrence and mechanism of leaching from foliage by aquous solutions and the nature of the materials leached. M.Sc. thesis, Cornell Univ. Ithaca, N. Y.

Morgan, J. V., and H. B. Tukey, Jr. 1964. Characterization of leachate from plant foliage. Plant Physiol. 39: 590-593.

Munn, D. A., and W. A. Jackson. 1978. Nitrate and ammonium uptake by rooted cuttings of sweet potato. Agron. J. 70: 312-316.

Nelson, S. H. 1959. Mist propagation of evergreens in the greenhouse during winter. Proc. Int. Plant Prop. Soc. 9: 67-76.

Oertli, J. J., and O. R. Lunt. 1962a. Controlled availability fertilizers. Properties of coated fertilizer materials. Calif. Agr. 16: 4.

Oertli, J. J., and O. R. Lunt. 1962b. Controlled-release of fertilizer minerals by incapsulating membranes. I Factors influencing the rate of release. Soil Sci. Soc. Amer. Proc. 26: 579-583.

Paparozzi, E. T., and H. B. Tukey, Jr. 1979. Foliar uptake of nutrients by selected ornamental plants. J. Amer. Soc. Hort. Sci. 104: 843-846.

Patel, A. J., and G. C. Sharma. 1977. Nitrogen release characteristics of controlled-release fertilizers during a four month soil incubation. J. Amer. Soc. Hort. Sci. 102: 364-367.

Paul, J. L., and A. T. Leiser. 1968. Influence of calcium saturation of sphagnum peat on the rooting of five woody species. Hort. Res. 8: 41-50.

Paul, J. L., and L. V. Smith. 1966. Rooting of chrysanthemum cuttings in peat as influenced by calcium. Proc. Amer. Soc. Hort. Sci. 89: 626-630.

Pearse, H. L. 1943. The effect of nutrition and phytohormones on the rooting of vine cuttings. Ann. Bot. n.s. 7: 123-132.

Phillips, I. D. J. 1964. Root-shoot hormone relations. II Changes in endogenous auxin concentration produced by flooding of root system in Helianthus annus. Ann. Bot. n.s. 28: 37-41.

Piper, C. S. 1944. Soil and plant analysis. Interscience Publishers, Inc. N. Y.

Prasad, M., and M. J. Woods. 1971. Release characteristics of nitrogen fertilizers in peat and sand. J. Agr. Food Chem. 19: 96-98.

Preston, W. H., Jr., J. B. Shanks, and P. W. Cornell. 1953. Influence of mineral nutrition on production, rooting, and survival of cuttings of azaleas. Proc. Amer. Soc. Hort. Sci. 61: 499-507.

Raabe, R. D., and J. Vlamis. 1966. Rooting failure of chrysanthemum cuttings resulting from excess sodium or potassium. Phytopathology 56: 713-717.

Raviv, M., and Y. Regev. 1980. Slow-release fertilizer as a source of nutrients to chrysanthemum cuttings being rooted under intermittent mist (in Hebrew) (Abstr.). Hassadeh 6: 119-121.

Reavis, R., S. Shoup, and C. E. Whitcomb. 1980. Measuring soluble salt levels of Osmocote and micromax and their effects on growth of tree seedlings. Okl. Agr. Expt. Sta. Res. Rpt. P-803: 70-71.

Reid, D. M., and A. Crozier. 1971. Effect of waterlogging on gibberellin content and growth of tomato plants. J. Exp. Bot. 22: 39-41.

Richards, D., and C. E. Whitcomb. 1979. Effects of nutrition during propagation and date of planting-out on quality of nursery stock. Okl. Agr. Expt. Sta. Res. Rpt. P-791: 36-38.

Richards, D., and C. E. Whitcomb. 1980. Effects of nutrition during propagation and date of planting-out on quality of nursery stock. Okl. Agr. Expt. Sta. Res. Rpt. P-803: 42-45.

Ross, R. G., and D. H. Webster. 1976. Effect of fungicides on the nutrient content of apple leaves. Can. J. Plant Sci. 56: 1001-1002.

Schulte, J. R., and C. E. Whitcomb. 1973. Effects of slow-release fertilizers on the rooting of cuttings and subsequent growth response. Okl. Agr. Expt. Sta. Res. Rpt. P-691: 28-30.

Self, R. L., and C. T. Pounders, Jr. 1978. Rooting of cuttings directly in growing medium containing fertilizer. Amer. Camellia Yearbook 1978: 20-22.

Sharma, G. C. 1979. Controlled-release fertilizers and horticultural applications. Scientia Hort. 11: 107-129.

Sharpe, R. H. 1955. Mist propagation studies with emphasis on mineral content of foliage. Proc. Florida State Hort. Soc. 68: 345-347.

Sheppard, W. J., C. H. Gilliam, and T. A. Fretz. 1979. Macronutrient stability during overwintering of Royal Beauty cotoneaster and Andorra juniper. HortScience 14: 751-753.

Simpson, B., A. E. Einert, and L. H. Hileman. 1975. Effects of Osmocote application method on soil and plant nutrient levels and flowering of potted chrysanthemums. Flor. Rev. 156: 27-28, 68-69.

Skoog, F., and C. Tsui. 1948. Chemical control of growth and bud formation in tobacco stem and callus. Amer. J. Bot. 35: 782-787.

Smith, E. M. 1973. A survey of the foliar mineral element content of nursery-grown ornamentals. Research summary. Ohio Agr. Res. Dev. Center 71: 29-32.

Smith, E. M. 1978. Foliar analysis survey of woody ornamental plants. Research summary. Ohio Agr. Res. Dev. Center 236: 30-33.

Smith, E. P. 1926. Acidity of the medium and root production in coleus. Nature 117: 339-340.

Smith, N. G., and P. F. Wareing. 1972. Rooting of hardwood cuttings in relation to bud dormancy and the auxin content of the excised stems. New Phytol. 71: 63-80.

Snyder, W. E. 1953. The fundamentals of juniper propagation. Proc. Int. Plant Prop. Soc. 3: 67-80.

Snyder, W. E. 1954. Possibilities with mist propagation. Proc. Int. Plant Prop. Soc. 4: 89-103.

Snyder, W. E. 1965. A history of mist propagation. Proc. Int. Plant Prop. Soc. 15: 63-67.

Snyder, W. E. 1974. Physiology of rooting. Proc. Int. Plant Prop. Soc. 24: 384-387.

Sokratova, E. G. 1965. The water permeability and aeration of substrates for rooting softwood cuttings under artificial mist (cited by Hamilton and Johnson 1978). Dokl., Mosk. Skh. No. III: 45-52.

Sorensen, D. C., and G. D. Coorts. 1966. Influence of mist fertilization on rooting and chemical composition of selected woody ornamental plants. Proc. XVIIth Int. Hort. Cong. Vol 1: 363.

Sorensen, D. C., and G. D. Coorts. 1968. The effect of nutrient mist on propagation of selected woody ornamental plants. Proc. Amer. Soc. Hort. Sci. 92: 696-703.

Spiegel, R. P. 1954. Auxins and inhibitors in canes of Vitis. Bull. Res. Coun. Israel 4: 176-183.

Staay, R. Van Der. 1979. pH and salinity demonstration and interpretation. Proc. Int. Plant Prop. Soc. 29: 574-576.

Starring, C. C. 1923. Influence of the carbohydrate-nitrate content of cuttings upon the production of roots. Proc. Amer. Soc. Hort. Sci. 20: 288-292.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach, 2nd ed. McGraw-Hill Co. N. Y.

Steyn, W. J. A. 1959. Leaf analysis. Errors involved in the preparative phase. J. Agr. Food Chem. 7: 344-348.

Still, S. M. 1981. Effects of cutting dates and rates of IBA on the rooting of four Tilia taxa. Ohio Agr. Res. Dev. Center Res. Circ. 263: 20-22.

Swanson, B. T. 1974. Ethrel as an aid in rooting. Proc. Int. Plant Prop. Soc. 24: 351-361.

Swanson, B. T., and J. L. Davis. 1977. The rooting of Plectranthus australis (swedish ivy) as affected by nutrient deficiencies and aeration in the rooting medium. Plant Prop. 23: 12-16.

Swanson, B. T., R. J. Fullerton, and S. Ramer. 1982. Are some slow-release fertilizers better. Amer. Nurseryman 158: 89-95.

Templeton, H. 1953. The phytotektor method of rooting cuttings. Proc. Int. Plant Prop. Soc. 3: 51-52.

Thimann, K. V. 1935. On the plant growth hormone produced by Rhizopus suinus. J. Biol. Chem. 109: 279-291.

Ticknor, R. L. 1980. Rooting of Ilex not increased in Osmocote amended propagation medium. Orn. N.W. Newsletter 4: 8-9.

Tisdale, S. L., and W. L. Nelson. 1975. Soil fertility and fertilizers. Macmillan, N. Y.

Tukey, H. B., Jr. 1970. The leaching of substances from plants. Ann. Rev. Plant Physiol. 21: 305-324.

Tukey, H. B., Jr. 1975. Regulation of plant growth by rain and mist. Proc. Int. Plant Prop. Soc. 25: 403-406.

Tukey, H. B., Jr. 1978. The effects of intermittent mist on cuttings. Acta Hort. 79: 49-56.

Tukey, H. B., Jr. 1979. Back to the basics of rooting. Proc. Int. Plant Prop. Soc. 29: 422-427.

Tukey, H. B., Jr., and R. A. Mecklenburg. 1964. Leaching of metabolites from foliage and subsequent reabsorption and redistribution of the leachate in plants. Amer. J. Bot. 51: 737-742.

Tukey, H. B., Jr., and J. V. Morgan. 1964. The occurrence of leaching from above-ground plant parts and the nature of the materials leached. Proc. XVIth Int. Hort. Cong. Vol 4: 153-159.

Tukey, H. B., Jr., H. B. Tukey, and S. H. Wittwer. 1958. Loss of nutrients by foliar leaching as determined by radioisotopes. Proc. Amer. Soc. Hort. Sci. 71: 496-506.

Van Goor, B. J., and D. Wiersma. 1974. Redistribution of potassium, calcium, magnesium and manganese in the plant. Physiol. Plant. 31:163-168.

Ward, J. D., and C. E. Whitcomb. 1976. Effects of Osmocote in the rooting medium and different nutrient sources on growth of japanese holly liners. Okl. Agr. Expt. Sta. Res. Rpt. P-741: 65-70.

Ward, J. D., and C. E. Whitcomb. 1977. Nutrition of Ilex crenata 'Hetzi' during propagation of production. Okl. Agr. Expt. Sta. Res. Rpt. P-760: 57-65.

Ward, J. D., and C. E. Whitcomb. 1979. Nutrition of japanese holly during propagation and production. J. Amer. Soc. Hort. Sci. 104: 523-526.

Wareing, P. F. 1973. Hormones and propagation. Proc. Int. Plant Prop. Soc. 23: 212-219.

Waters, W. E. 1960. The effects of potassium source and soil mixtures on leaching of fertilizer salts from clay pots. Proc. Florida State Hort. Soc. 73: 384-389.

Weiser, C. J., and L. T. Blaney. 1960. The effects of boron on the rooting of english holly cuttings. Proc. Amer. Soc. Hort. Sci. 75: 704-710.

Whitcomb, C. E., J. Gibson, and A. Storjohann. 1978. Effects of Osmocote use in rooting mediums. Amer. Nurseryman 148: 11, 66-68.

Williams, D. J. 1980. How slow-release fertilizers work. Amer. Nurseryman 151: 90-97.

Williams, R. F., and T. E. Bilderback. 1980. Factors affecting rooting of Rhododendron maximum and Kalmia latifolia stem cuttings. HortScience 15: 827-828.

Wittwer, S. H., and F. G. Teubner. 1959. Foliar absorption of mineral nutrients. Ann. Rev. Plant Physiol. 10: 13-27.

Wott, J. A., and H. B. Tukey, Jr. 1965. Propagation of cuttings under nutrient mist. Proc. Int. Plant Prop. Soc. 15: 86-94.

Wott, J. A., and H. B. Tukey, Jr. 1966. Propagation with nutrient mist. Proc. XVIIth Int. Hort. Cong. Vol 1: 364.

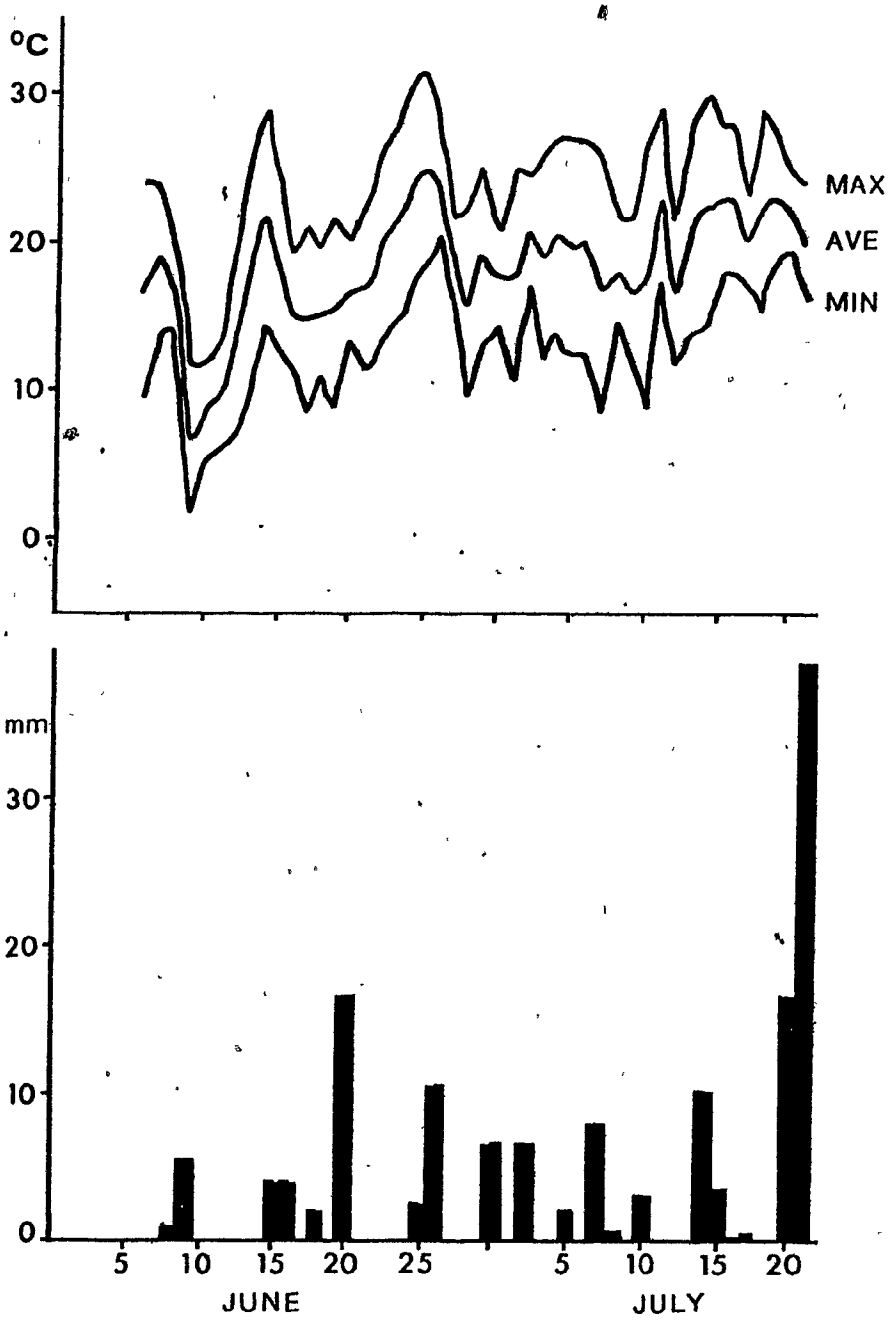
Wott, J. A., and H. B. Tukey, Jr. 1967. Influence of nutrient mist on the propagation of cuttings. Proc. Amer. Soc. Hort. Sci. 90: 454-461.

Wott, J. A., and H. B. Tukey, Jr. 1969. Absorption of phosphorus by Chrysanthemum morifolium cuttings propagated under nutrient mist. J. Amer. Soc. Hort. Sci. 94: 382-384.

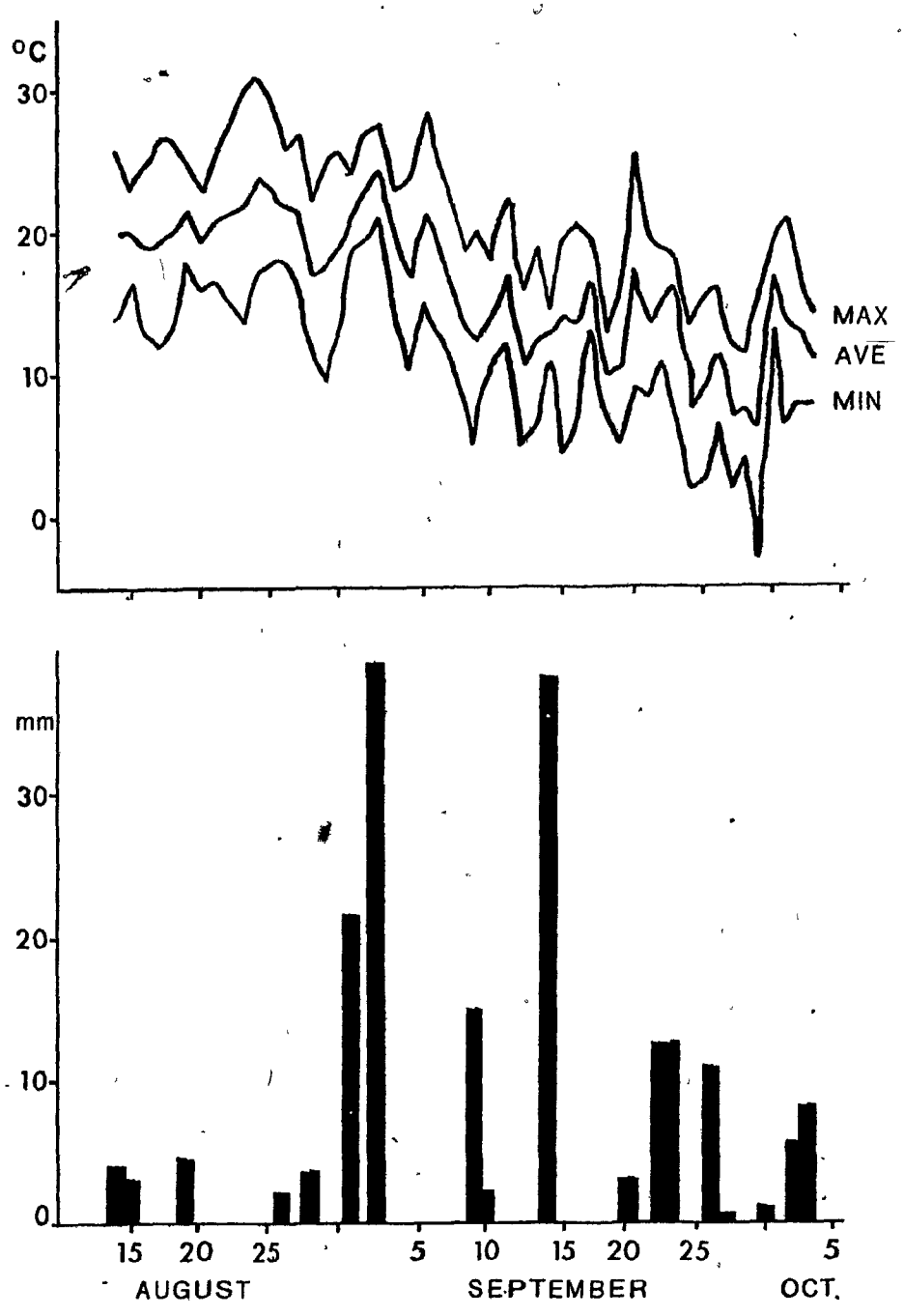
Wott, J. A., and H. B. Tukey, Jr. 1973. The absorption of nutrient mist into cuttings. Proc. Int. Plant Prop. Soc. 23: 141-147.

Zimmerman, P. W. 1925. Vegetative plant propagation with special reference to cuttings. Proc. Amer. Soc. Hort. Sci. 22: 223-228.

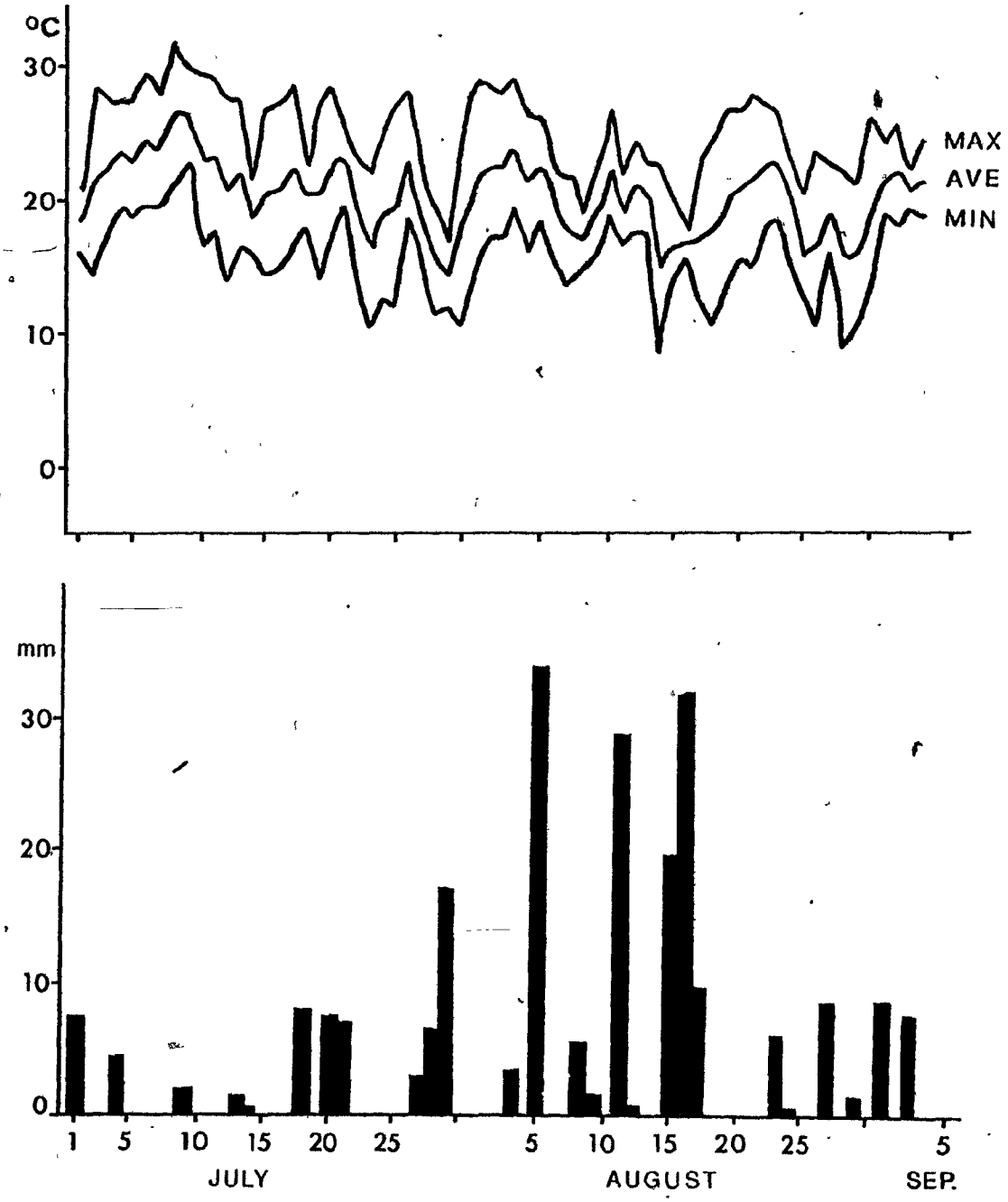
Zimmerman, R. H. 1958. Effects of liquid fertilizers on rooting of cuttings. Proc. Int. Plant Prop. Soc. 8: 162-164.



Appendix Fig. 1. Temperature (top) and rainfall (bottom) data from June 6, 1980 to July 21, 1980.



Appendix Fig. 2. Temperature (top) and rainfall (bottom) data from August 14, 1980 to October 3, 1980.



Appendix Fig. 3. Temperature (top) and rainfall (bottom) data from July 1, 1981 to September 3, 1981.