THE EFFECTS OF NITROGEN, PHOSPHORUS AND POTASSIUM ON THE PROPAGATION AND SUBSEQUENT GROWTH OF THREE WOODY ORNAMENTALS

By

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Stillwater, Oklahoma

1981

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1984

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ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my family for their support throughout my college days.

Sincere appreciation is also expressed to my major professor, Dr. Carl E. Whitcomb, for his sharing of knowledge, assistance, and friendship during my graduate work.

Thanks to advisory committee members, Dr. J. Q. Lynd and Dr. Michael W. Smith, for their guidance.

Finally, thanks also to nursery research members, Charlie Gray and Billy Cavanaugh, for their help and assistance.

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CHAPTER I

INTRODUCTION

Stem cuttings are the most widely used form of reproducting woody shrubs by nurserymen. The benefits and ease of asexual propagation have lead to much research and advances in this technique.

There are many internal [physiological] and external [environmental] factors which affect how easily a cutting will root, or in some cases whether the cutting will root at all. Several of the internal factors such as hormones, cofactors, juvenility, and the carbohydrate to nitrogen ratio of the cutting are partially understood. The external factors are the conditions which have been studied the most, probably because of a better understanding of them, and they are easier to regulate.

The propagator may control such environmental factors as temperature, light, moisture, rooting media, stock plant nutrition, and the nutrition of the cutting. Bottom heat is the most economical and effective method to heat a propagation structure. With bottom heat the rooting medium stays warm while the surrounding air temperature is normally cooler. According to Hartmann and Kester (11), excessively high are temperatures tend to promote bud development before roots form and increase water loss from the leaves.

Light intensity is important to the cutting during propagation because carbohydrates must be manufactured by the leaves to promote new root growth. Whitcomb (38), notes that the light intensity the cutting receives in propagation should be similar to the light intensity in the landscape prior to separating the cutting from the parent. The moisture and humidity the cuttings receive can be controlled by intermittent mist systems, in which water is applied at frequent short intervals. This reduces the water loss from the cutting until roots are formed.

Studies have shown that many different media work well for rooting cuttings. Combinations such as peat and perlite, peat and vermiculite, or peat and ground pine bark in a 1:1 ratio have worked well. One hundred percent peat has also worked well; however, results will vary with the type of peat. In general, the rooting medium should provide good drainage and aeration, and be free of pathogens. Stock plant nutrition has been very beneficial in increasing rooting and quality of cuttings (19, 26, 30). These studies have shown that it is mainly nitrogen that produces beneficial results.

During the last 20 years several studies have dealt with supplying the cutting with nutrients during propagation. Initially mist nutrition was tried. Wott and Tukey (41) reported that nutrient mist had little effect on root initiation, but did influence the percentage which rooted, as well as root quality. Recently, slow-release nutrients have been added to the media and have proven beneficial to rooting and growth of cuttings (23, 38). Slow-release fertilizers have been shown to be species dependent in stimulating root development during propagation. However, the later growth of the transplated liners is greater increased by the mineral nutrition which the cutting received during propagation.

Research is continuing to determine the optimum formulation of N-P-K slow-release fertilizer to be added to the propatation medium. The objective of this study was to test three rates of nitrogen, five rates of phosphorus, and two rates of potassium slow-release fertilizer incorporated into the rooting medium on the propagation and subsequent growth of three woody ornamental shrubs.

CHAPTER II

LITERATURE REVIEW

Anatomical Factors of Propagation by Cuttings

In propagation by stem cuttings, it is necessary to form a new root system. Rooting can be separated into root initiation and root development. This can occur because certain cells within the plant have the ability to differentiate from stem parenchyma cells into root initials (11). The location inside the stem where adventitious roots are formed from root initials is not precisely known. However, it is thought that in woody perennial plants root initials originate near the pholem (11, 35).

Girouard (8) notes that adventitious roots form near differentiating tissues of the vascular system so to maintain a rapid vascular connection between the new roots and the stem. Hartmann and Kester (11) list three stages in the development of adventitious roots: (1) cellular differentiation followed by the initiation of meristimatic cells into root initials; (2) the differentiation of these cells into root primordia; and (3) the growth and emergence of new roots, and formation of vascular connections with the vascular tissues of the cutting.

Timing of Taking Cutting as Related to Physiological Factors

Time of year influences the success of rootability. Komosorov (20) suggests that the amount of lignification of the shoot plays an important part in how well a cutting will root. He states that the stage when the shoot stem shows good flexibility, axillary buds are formed, and upper leaves reach their normal size and coloration produce the highest percentage of rooting under optimum environmental conditions.

Hess (12, 13, 14) discovered that substances other than hormones influence the rootability of cuttings. These compounds serve as cofactors to IAA and promote rooting. Choong (5) related the levels of cofactors in cuttings at different times of the year to the success of rooting. He explained that increased levels of cofactors in September may be why rooting is best achieved on most hardwood cuttings taken in late summer or fall. Roberts (28) found that the buds on douglas fir, *Pseudotsuga menziesii*, contain at various times of the year, rooting inhibitors and promoters.

Carbohydrate to nitrogen ratios in the stem of the cutting have been shown to influence rooting (21, 32). This C/N ratio of the cutting can be controlled through stock plant nutrition. Blazich and Wright (2) analyzed cuttings of *Ilex crenata* during propagation to determine whether mobilization of nutrients occurred to the base of the stem. They reported that no mobilization occurred, suggesting that cuttings be taken from stock plants with sufficient nutrition. Other studies (18, 19, 26, 30) have shown the importance of stock plant nutrition in obtaining good quality liners. Although high carbohydrates and low nitrogen favor good rooting, sufficient nitrogen must be available to the cutting for shoot growth once the cutting roots.

The ease with which a cutting roots can be related to the age of the stock plant (11). The capacity for cuttings to root is generally reduced with plant age (20). Hartmann and Kester (11) suggest that this reduction may be due to increased levels of inhibitors, and a reduction in cofactors as the plant ages. According to Komosorov (20) this difference in rooting potential due to plant age is not associated with a reduction in metabolism, but because of early specialization of cells and tissues which are unfavorable to root primordia and a loss of plasticity.

Propagation Media

The rooting media influences the rooting of cuttings (16, 22, 25). Chadwick (4) found that a mixture of sand and peat moss provided a higher percent of cuttings rooted than either sand or peat alone in 17 of 26 deciduous species. Rauch (27) evaluated the effect of various rooting media (sand, perlite, sand-perlite, sand-peat, peat-perlite) on the rooting and root quality from several easy-to-root species. He found that no one media was best for all species tested.

Hickman (15) reported that 1:1 peat-perlite mix provided a greater visual root grade of lacebark elm cuttings, than mixes containing either a 2:1:1 peat-bark-perlite, or a 100% bark mix.

Diver and Whitcomb (7) compared 100% peat to a 50:50 peat-perlite mixture and found that the 100% peat provided a significantly better root system, and increased the number of branches of <u>Juniperus procumbens</u> after one growing season. Threadgill (33), working with four evergreen shrubs, observed that 100% peat in the propagation mix decreased root grade and weight of rooted cuttings, compared to cuttings propagated in a 50:50 peat-perlite mix. However, the subsequent growth at the end of the growing season was significantly better for all species propagated in 100% peat.

Hartmann and Kester (11) indicate that the propagation medium must provide support for the cutting, retain moisture, be sufficiently porus to allow drainage and gas exchange, and be free of disease organisms and weed seeds. The expense and availability are also factors the nurseryman must consider.

Nutrition During Propagation

Tukey (34) found that mineral nutrients and metabolites were leached from the leaves of the cutting under mist. Wittmer and Tenbner (40) showed plants may absorb mineral nutrients through their leaves and stems. In the mid-1960's nutrient mist was shown to benefit cuttings during propagation (31, 41). However, algae growth on the surface of the rooting media, and disease problems lead to the search for other alternatives.

McGuire and Bunce (23) reported the use of slow-release fertilizer incorporated into the rooting medium. Deen (6) studied the effects of adding 113.4 grams per 121.088 liters (4 oz./bushel) of osmocote 18-6-12 into the rooting medium. He found that after five weeks under mist, Cotoneaster cuttings which received osmocote had developed side shoot growth, and were taller than cuttings without osmocote. Schulte and Whitcomb (29) tested the incorporation of osmocote 18-6-12 at 0, 200, 400, and 600 grams per 35.2 liters of medium. They reported that Ilex cornutu 'Burford' increased in root quality and percentage rooted as the level of osmocote increased up to 400 grams. Schulte and Whitcomb concluded that the osmocote may have stimulated root initiation, or root development following root initiation.

Gouin (10) evaluated the cuttings of four cultivars of Rhododendron top-dressed with either 0, 7, or 14 grams of 19-6-12 osmocote per $0.093m^3$. He noted that all treated cuttings developed heavier root systems, and produced more top growth than cuttings not receiving osmocote. Glenn, Hogan, and Whitcomb (9) studying rates incorporated into the rooting medium, reported an increase in root grade of Ilex cornuta 'Buford' as the level of osmocote increased. Johnson and Hamilton (17) used two osmocote formulations (18-6-12 and 14-14-14) top-dressed at two rates each on rooting and leaf nutrient composition of Ligustrum japonicum and Juniperus conferta. They found that osmocote had little influence on rooting of either species compared to an untreated control. The high rates of 14-14-14 however, inhibited root development due to its rapid initial release which the authors thought burned newly formed roots. After root development and nutrient uptake occurred, osmocote 18-6-12 increased top growth. Leaf tissue analysis showed that nitrogen and phosphorus was greater in osmocote treated cuttings compared to unfertilized controls.

Ward and Whitcomb (36), working with Ilex crenata 'Hetzi', found that incorporating osmocote 18-6-12 at 200 to 400 grams per 35.2 liters of rooting medium greatly enhanced the growth of the liner after transplanting into larger containers. They concluded that salable one gallon plants could be produced in a single growing season if the cuttings were propagated in osmocote 18-6-12 incorporated media, and produced in a larger container using a slow-release fertilizer program.

Whitcomb, Gibson and Storjohann (37) studied three different osmocote formulations 19-6-12 (3-4-months), 18-6-12 (6-9 months), and 18-5-11 (12-14 months), each at three rates incorporated into either a peat and perlite or peat and ground pine bark (1:1) mix. Osmocote rates were 4.76, 7.14, and 9.52 kg/m^3 (8, 12, and 16 lbs/yd^3), Species evaluated were Lagerstroemia indica, Euonymus fortunei 'Coloratus', and Ligustrum vicaryi. Euonymus had the greatest root weight and grade with the 18-6-12 formulation, and 7.14 k/m^3 (12 lbs/yd^3). Ligustrum increased in top weight, root weight, and visual root grade with either the 4.76 or 7.14 kg/m^3 (8 or 12 lbs/yd^3) rates. The 18-6-12 formulation consistently produced the greatest top weight and best root grade. With Lagerstroemia, the number of bud breaks increased as the rate of osmocote increased. However, top and root weight and visual root grade were not affected. Ligustrum and Lagerstroemia liners were later transplanted into one gallon containers and grown through the summer. At the end of the growing season, the osmocote which was applied during propagation had a substantial effect on plant growth. This was thought to be due to the absorption of nutrients by the cutting following rooting.

Similar results were discovered by Whitcomb and Richards (39). They compared different transplanting dates of liners propagated in either 0, 6, 9, or 12 lbs/yd^3 of osmocote 18-6-12. With both Juniperus chinensis 'pfitzeriana aurea' and Ilex cornuta 'Bufordi nana', osmocote incorporated into the rooting medium increased the number of branches over the control at the end of the growing season. Carney and Whitcomb (3) used osmocote 27-12-0 at four levels of actual nitrogen 0, 0.6 kg/m^3 (1.08 lbs/yd^3), 1.0 kg/m^3 (1.80 lbs/yd^3), and 1.5 kg/m^3 (2.52 lbs/yd^3) with osmocote 0-0-46 at four levels of actual potash 0, 0.45 kg/m^3 (0.72 lbs/yd^3), 0.72 kg/m^3 (1.20 lbs/yd^3), and 1.10 kg/m^3 (1.68 lbs/yd^3) incorporated into the propagation medium. Test plants studied were Ilex crenata 'Hetzi', Pyracantha coccinea 'Wateri', and Rhododendron X 'Fashion'. They found that each increasing level of nitrogen in the propagation mix significantly increased plant growth. No benefit was observed from potassium. The authors noted that phosphorus was an uncontrolled variable in osmocote 27-12-0 and may have interacted with nitrogen.

Babcock (1), working with tree seedlings during propagation, compared three rates of actual nitrogen from osmocote 26-0-0 at 0.417 kg/m^3 (0.7 lbs/yd^3), 0.833 kg/m^3 (1.4 lbs/yd^3), and 1.25 kg/m^3 (2.1 lbs/yd^3) with three levels of P_2O_5 from 0-46-0 uncoated triple-superphosphate at 0, 0.357 kg/m^3 (0.6 lbs/yd^3), and 0.714 kg/m^3 (1.2 lbs/yd^3) with three rates of K_2O from osmocote 0-0-45 at 0, 0.357 kg/m^3 (0.6 lbs/yd^3), and 0.714 kg/m^3 (1.2 lbs/yd^3). He observed that in both the propagation phase, and the production phase, the greatest plant response was from phosphorus. As the phosphorus level increased from 0 to 0.6 lbs/yd^3, a significant increase in plant growth occurred for all variables measured. He concluded that as long as the optimum level of phosphorus was present, the nitrogen and potassium levels were less critical.

CHAPTER III

METHODS AND MATERIALS

Experiment One

Propagation Phase

Hardwood cuttings of three ornamental shrub species were used to evaluate the effects of various levels of nitrogen, phsophorus, and potassium in factorial combination during propagation. Terminal stem cuttings were taken from stock plants of mojave pyracantha, *Pyracantha* X 'Mojave', hetzi japanese holly, *Ilex crenata* 'Hetzi', and tamarix juniper *Juniperus sabina* 'Tamariscifolia' on November 14-19, 1982.

Cuttings approximately 10 cm (4 in.) long with similar stem calipars were taken to insure uniformity. Tamarix juniper cuttings received 1.6 percent, or 16,000 ppm, indole butyric acid (IBA) talc powder. Propagation tray cells were 5.08 cm (2 in.) x 5.08 cm (2 in.) tapering to a 3.6 cm (1.4 in.) bottom x 7.6 cm (3 in.) deep. The propagation medium was 100 percent peat moss.

Propagation trays were placed on raised greenhouse benches in a fiberglass covered, quonset-type greenhouse. Intermittent mist was applied through overhead lines every 8 minutes for 4 seconds. Bottom heat was supplied from a gas fired heater through a plastic convection tube beneath the benches. The temperature was maintained at a minimum of 20° C (68° F) and a maximum of 29° C (85° F). After rooting and evaluation, plants were moved to a solar floor-heated greenhouse to harden off before transplanting.

Experimental Treatments

Experimental treatments were three levels of nitrogen, five levels of phosphorus, and two levels of potassium in factorial combination incorporated into the propagation medium. The nitrogen source was a plastic resin coated, (6-9 mo.) slow-release fertilizer (26-0-0).[1] The nitrogen was in the form of ammonium nitrate (NH_4NO_3) 15.5 percent and ammonium sulfate (NH_4SO_4) 10.5 percent. The phosphorus source was uncoated triple-super phosphate (0-46-0). The potassium source was potassium sulfate (K_2SO_4) plastic resin coated slow-release (6-9 mo.), (0-0-45).[2]

The levels of nitrogen, phosphorus, and potassium are shown in Table I. The amounts of elemental nitrogen, phosphorus, and potassium listed are comparable to that found in 0, 2.4, and 4.8 kg/m^3 (0, 4, and 8 lbs/yd^3) of osmocote 18-6-12. This formulation has been used successfully in numerous studies (24, 29, 36, 37, 39). Micromax micronutrients[3] at the rate of 0.6 kg/m^3 (1 lb/yd^3) was incorporated into all treatments. Osmocote 18-2.64-10 (18-6-12) at 2.4 kg/m^3 (4 lbs/yd^3) the most widely used fertilizer used in propagation, and osmocote 27-5.28-0 (27-12-0) at 1.5 kg/m^3 (2.5 lbs/yd^3) served as two controls.

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[1]A product of Sierra Chemical Company, Milipitas, California.

[2]Ibid.

[3]Ibid.

TABLE I

LEVELS OF NITROGEN, PHOSPHORUS, AND POTASSIUM INCORPORATED DURING PROPAGATION OF THE FIRST EXPERIMENT

Level	Nitrogen Levels			
	26-0-0 Bulk		Nitrogen	
1	0.0	0.0	0.0	0.0
2	1.60 kg/m^3	(2.69 lbs/yd^3)	0.417 kg/m^3	(0.7 lbs/yd^3)
3	3.20 kg/m^3	(5.38 lbs/yd^3)	0.833 kg/m^3	(1.4 lbs/yd^3)

Level	Phosphorus Levels			
	0-20-0 Bulk		Elemental P	P_2O_5
1	0.0	0.0	0.0	0.0
2	0.388 kg/m^3	(0.652 lbs/yd^3)	0.078 kg/m^3	(0.3 lbs/yd^3)
3	0.776 kg/m^3	(1.304 lbs/yd^3)	0.157 kg/m^3	(0.6 lbs/yd^3)
4	1.164 kg/m^3	(1.956 lbs/yd^3)	0.236 kg/m^3	(0.9 lbs/yd^3)
5	1.940 kg/m^3	(3.261 lbs/yd^3)	0.393 kg/m^3	(1.5 lbs/yd^3)

Level	Potassium Levels			
	0-0-37 Bulk		Elemental K	K_2O
1	0.0	0.0	0.0	0.0
2	0.793 kg/m^3	(1.333 lbs/yd^3)	0.296 kg/m^3	(0.6 lbs/yd^3)

Treatments were mixed in with the propagation medium in a rotating drum concrete mixer to insure uniform distribution. The study was conducted as a randomized complete block with four sub-samples and six replications.

On January 25, 1983, nine weeks after sticking the pyracantha cuttings, they were evaluated for visual root grade. Japanese holly cuttings were evaluated February 6, 1983, 11 weeks after sticking. Because very few of the tamarix juniper cuttings rooted, they were eliminated from the study.

Production Phase

Liners of two of the four sub-samples were transplanted on April 22-23, 1983. Japanese holly liners were potted into 3.8 liter (one-gallon) black rigid containers and placed in a quonset structure covered with 30 percent shade. The pyracantha liners were transplanted into 7.6 liter (two-gallon) white-on-black poly bags, and grown on a container bed under full sun.

Irrigation was by overhead sprinklers at approximately 2.5 cm (1 in.) per application. The growth medium in the production phase consisted of a 3:1:1 pine bark, peat, and sand mix. Incorporated into the medium was osmocote 17-3-10 (17-7-12) (12 mo.) at 8.3 kg/m^3 (14 lbs/yd^3), micromax micronutrient at 0.9 kg/m^3 (1.5 lbs/yd^3), and dolomite at 4.8 kg/m^3 (8 lbs/yd^3). Ronstar (oxydiazon) two percent granular was applied at 8.9 kg/ha (8 lbs/a) for weed control.

Pyracantha and japanese holly were pruned lightly on April 25, 1983 to promote lateral branching. Mojave pyracantha was spaced approximately .305 m X .305 m (1 ft. x 1 ft.) on August 19, 1983 to allow for maximum growth.

Final evaluation of mojave pyracantha occurred on October 15, 1983. Height, stem caliper, fresh top and root weights were determined. A final evaluation for hetzi japanese holly was taken on November 3, 1983. Branch number, fresh top and root weights were recorded.

Experiment Two

Propagation Phase

A second study was conducted to test the effects of nitrogen, phosphorus, and potassium during propagation on a species propagated by softwood cuttings. Winter honeysuckle (Lonicera fragrantissima) cuttings were taken May 20, 1983, and treated with a 0.3 percent (3000 ppm) IBA talc powder. The methods used were the same as in experiment one.

Experimental treatments were the same as in the first experiment (Table I). The rates of the controls were modified, however, to include 4.76 kg/m^3 (8 lbs/yd^3) 18-2.64-10, and 3.0 kg/m^3 (5.0 lbs/yd^3) 27-5.28-0. Another control, osmocote 13-5.72-11 (13-13-13) at 3.0 kg/m^3 and 6.5 kg/m^3 (5 and 11 lbs/yd^3) was added to the study.

A visual root grade was taken on July 27, 1983, after nine weeks. A grading scale of one to ten with one being no roots, and ten being a fully developed, fibrous root system was used.

Production Phase

Two sub-samples from 11 selected treatments were transplanted on July 28, 1983, into black rigid 3.8 liter (one-gallon) containers, and placed onto the production bed. The treatments chosen were levels two and three of nitrogen, with levels one, two and three of phosphorus, at the second level of potassium (Table II). The 18-2.64-10 and 13-5.72-11 controls at both rates were included. Liners were transplanted into the standard 3:1:1 mix, receiving the same rates of nutrients as in experiment one.

Study two was terminated on December 10, 1983. Branch number, top and root weights were taken.

TABLE II

LEVELS OF NITROGEN, PHOSPHORUS, AND POTASSIUM INCORPORATED DURING PROPAGATION OF THE SECOND EXPERIMENT

Level	Nitrogen Levels: 26-0-0 Bulk		Nitrogen	
2	1.60 kg/m^3	(2.69 lbs/yd^3)	0.417 kg/m^3	(0.7 lbs/yd^3)
3	3.20 kg/m^3	(5.38 lbs/yd^3)	0.833 kg/m^3	(1.4 lbs/yd^3)

Level	Phosphorus Levels: 0-20-0 Bulk		Elemental P	P_2O_5
1	0.0	0.0	0.0	0.0
2	0.388 kg/m^3	(0.652 lbs/yd^3)	0.078 kg/m^3	(0.3 lbs/yd^3)
3	0.776 kg/m^3	(1.304 lbs/yd^3)	0.157 kg/m^3	(0.6 lbs/yd^3)

Level	Potassium Levels: 0-0-37 Bulk		Elemental K	K_2O
2	0.793 kg/m^3	(1.333 lbs/yd^3)	0.296 kg/m^3	(0.6 lbs/yd^3)

CHAPTER IV

RESULTS AND DISCUSSION

Experiment One

Propagation Phase

Visual root grade of mojave pyracantha increased with increasing phosphorus up to P_3; 0.15 kg/m^3 (0.6 lbs/yd^3) where it peaked, and leveled off at the P_4; 0.23 kg/m^3 (0.9 lbs/yd^3), and P_5; 0.39 kg/m^3 (1.5 lbs/yd^3) rates (Table III).

TABLE III

EFFECTS OF PHOSPHORUS ON VISUAL ROOT GRADE OF MOJAVE PYRACANTHA AFTER THE NINE WEEK PROPAGATION PHASE

	Phosphorus Levels kg/m^3				
	1	2	3	4	5
	0.0	0.07	0.15	0.23	0.39
Visual Root Grade	3.4_a [z]	3.8_{ab}	4.4_c	4.1_{bc}	4.1_{bc}

[z]Means in a row followed by the same letter are not significantly different at the 0.5% level using a protected LSD.

Visual root grade of hetzi japanese holly increased as nitrogen increased from N_1 (zero) to N_2; 0.42 kg/m^3 (0.7 lbs/yd^3), with no further change at N_3; 0.83 kg/m^3 (1.4 lbs/yd^3) (Table IV).

TABLE IV

EFFECTS OF NITROGEN ON VISUAL ROOT GRADE OF HETZI JAPANESE HOLLY AFTER THE 11 WEEK PROPAGATION PHASE

	Nitrogen Levels kg/m^3		
	1 0.0	2 0.42	3 0.83
Visual Root Grade	4.3_a^z	5.0_b	5.0_b

[z]Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

Visual root grade of hetzi japanese holly revealed a significant NxPxK interaction (Table V). In order to separate the effects, the interaction was separated to test the NxP interaction at both levels of potassium, K_1 (zero), and K_2 0.29 kg/m^3 (0.6 lbs/yd^3) rates. Without potassium added to the propagation medium, the P_4 level of phosphorus was needed to reach the peak visual grade at the N_2 and N_3 levels (Table VI).

These findings contrast with Carney (3) who found that potassium incorporated into the propagation medium had little benefit on the rooting of cuttings.

TABLE V

ANALYSIS OF VARIANCE FOR VISUAL ROOT GRADE OF HETZI JAPANESE HOLLY AFTER THE 11 WEEK PROPAGATION PHASE

Source	df	SS	MS	F	$F_{.05}$
Total	179	240.539			
Rep	5	35.187	7.037	7.05*	2.21
TrT	29	60.632	2.0907	2.09*	1.46
N	2	18.340	9.170	9.19*	3.00
P	4	5.556	1.389	1.39	2.37
K	1	0.0002	0.0002	0.0002	3.84
NxP	8	9.696	1.212	1.21	1.94
NxK	2	1.624	0.812	0.18	3.00
PxK	4	8.389	2.097	2.10	2.37
NxPxK	8	17.025	2.128	2.13*	1.94
Error	145	144.718	0.998		

TABLE VI

INTERACTION OF NITROGEN x PHOSPHORUS WITH AND WITHOUT POTASSIUM ON THE VISUAL ROOT GRADE OF HETZI JAPANESE HOLLY AFTER THE 11 WEEK PROPAGATION PHASE

Without K		kg/m^3	Nitrogen Levels 1 (0.0)	Nitrogen Levels 2 (0.42)	Nitrogen Levels 3 (0.83)
Phosphorus Level	1	0.0	3.7_{a_1} [z][y]	4.7_{b_1}	$5.2_{b_{2,3}}$
	2	0.07	4.5_{a_1}	4.4_{a_1}	$4.6_{a_{1,2}}$
	3	0.15	4.2_{a_1}	5.2_{b_1}	$4.5_{ab_{1,2}}$
	4	0.23	4.4_{a_1}	5.4_{b_2}	5.6_{b_4}
	5	0.39	4.9_{b_2}	5.2_{b_1}	3.9_{a_1}

With K		kg/m^3	Nitrogen Levels 1 (0.0)	Nitrogen Levels 2 (0.42)	Nitrogen Levels 3 (0.83)
Phosphorus Level	1	0.0	$4.3_{a_{1,2}}$	4.3_{a_1}	5.6_{b_2}
	2	0.07	$4.3_{a_{1,2}}$	6.1_{b_2}	5.4_{b_2}
	3	0.15	$3.8_{a_{1,2}}$	4.8_{b_1}	$5.0_{b_{1,2}}$
	4	0.23	4.7_{a_2}	5.1_{a_1}	4.4_{a_1}
	5	0.39	3.7_{a_1}	4.3_{ab_1}	$4.8_{b_{1,2}}$

[z]Means in a row followed by the same letter are not significantly different at the .05% level.

[y]Means in a column followed by the same number are not significantly different at the .05% level.

Experiment Two

Propagation Phase

Visual root grade of winter honeysuckle increased from N_1 to N_2 (Table VII). Increasing nitrogen from N_2 to N_3 restricted root grade. Osmocote release rate is temperature related, and may have released sufficient nitrogen during the warm temperature in May to be detrimental to the softwood cuttings.

TABLE VII

EFFECTS OF NITROGEN ON VISUAL ROOT GRADE OF WINTER HONEYSUCKLE AFTER THE NINE WEEK PROPAGATION PHASE

	Nitrogen Levels kg/m^3		
	1 0.0	2 0.42	3 0.83
Visual Root Grade	5.6_a[z]	6.7_b	5.8_a

[z]Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

Experiment One

Production Phase

At the end of one growing season, growth of mojave pyracantha followed the same trend observed for the visual root grade at the end of the propagation phase. Increasing phosphorus from P_1 (zero), to

P_3, increased growth for all variables measured (Table VIII). Growth was restricted at the P_4 and P_5 rates on top weight, height, and root weight.

TABLE VIII

EFFECTS OF PHOSPHORUS ON MOJAVE PYRACANTHA AFTER ONE GROWING SEASON

	Phosphorus Levels kg/m^3				
	1	2	3	4	5
	0.0	0.07	0.15	0.23	0.29
Top Weight (g)	238.9_a[z]	271.2_b	294.7_b	284.9_b	262.1_{ab}
Height (cm)	93.0_a	94.5_{ab}	99.4_c	97.7_{bc}	93.8_{ab}
Stem Caliper (cm)	1.2_a	1.2_a	1.3_b	1.3_b	1.3_b
Root Weight (g)	79.8_a	101.1_{bc}	106.9_c	103.2_{bc}	93.8_b

[z]Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

Potassium increased height of mojave pyracantha (Table IX). As nitrogen increased from N_1 to N_2, a substantial increase in root weight of mojave pyracantha was observed with little change between N_2 and N_3 (Table X).

A significant NxPxK interaction occurred on top weight of hetzi japanese holly (Table XI). Using a separation to text NxP with and without potassium, a trend similar to visual root grade was observed

TABLE IX

EFFECTS OF POTASSIUM ON HEIGHT OF MOJAVE PYRACANTHA
AFTER ONE GROWING SEASON

	Potassium Levels kg/m^3	
	1	2
	0.0	0.29
Height (cm)	93.9_a^z	97.4_b

^{z}Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

TABLE X

EFFECTS OF NITROGEN ON ROOT WEIGHT OF MOJAVE PYRACANTHA
AFTER ONE GROWING SEASON

	Nitrogen Levels kg/m^3		
	1	2	3
	0.0	0.42	0.83
Root Weight (g)	88.7_a^z	100.2_b	101.9_b

^{z}Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

(Table XII). The higher rates of phosphorus (P_4 and P_5) were required to reach the peak means without potassium at the N_2 and N_3 rates. However, with potassium incorporated, although the highest mean was at the N_2P_4 rate, it was not significantly better than the second level of phosphorus at N_2.

TABLE XI

ANALYSIS OF VARIANCE FOR TOP WEIGHT OF HETZI JAPANESE HOLLY AFTER ONE GROWING SEASON

Source	df	SS	MS	F	$F_{.05}$
Total	179	60,931			
Rep	5	6,937	1,387	6.29*	2.21
TrT	29	22,041	760	3.45*	1.46
N	2	10,777	5,388	24.43*	3.0
P	4	2,197	549	2.49*	2.37
K	1	126	126	0.57	3.84
NxP	8	3,517	439	1.99*	1.94
NxK	2	746	373	1.69	3.0
PxK	4	1,131	282	1.28	2.37
NxPxK	8	3,544	443	2.01*	1.94
Error	145	31,953	220		

TABLE XII

INTERACTION OF NITROGEN x PHOSPHORUS WITH OR WITHOUT POTASSIUM ON THE TOP WEIGHT OF HETZI JAPANESE HOLLY AFTER ONE GROWING SEASON

Without K		kg/m^3	Nitrogen Levels 1 (0.0)	Nitrogen Levels 2 (0.42)	Nitrogen Levels 3 (0.83)
Phosphorus Level	1	0.0	$49.5_{a_{1,2}}$[z][y]	51.0_{a_1}	59.2_{a_1}
	2	0.07	62.0_{b_3}	45.6_{a_1}	69.8_{b_2}
	3	0.15	42.1_{a_1}	67.3_{b_2}	61.6_{b_1}
	4	0.23	46.9_{a_1}	75.6_{b_2}	78.5_{b_2}
	5	0.39	$57.2_{a_{2,3}}$	74.4_{b_2}	$67.8_{ab_{1,2}}$

With K		kg/m^3	Nitrogen Levels 1 (0.0)	Nitrogen Levels 2 (0.42)	Nitrogen Levels 3 (0.83)
Phosphorus Level	1	0.0	47.4_{a_1}	56.8_{ab_1}	66.8_{b_1}
	2	0.07	52.4_{a_1}	76.0_{b_2}	73.7_{b_1}
	3	0.15	45.4_{a_1}	$71.8_{b_{1,2}}$	70.0_{b_1}
	4	0.23	50.3_{a_1}	79.0_{b_2}	58.4_{a_1}
	5	0.39	48.0_{a_1}	$65.3_{ab_{1,2}}$	67.1_{b_1}

[z]Means in a row followed by the same letter are not significantly different at the .05% level.

[y]Means in a column followed by the same number are not significantly different at the .05% level.

Although NxPxK interaction for number of branches of hetzi japanese holly fell short of being significant at the .05 level, it was interesting to test NxP with and without potassium (Table XIII). Again, Table XIV shows that higher levels of phosphorus were needed at the second level of nitrogen to reach the high means without potassium, than when potassium was incorporated.

TABLE XIII

ANALYSIS OF VARIANCE FOR BRANCH NUMBER OF HETZI JAPANESE HOLLY AFTER ONE GROWING SEASON

Source	df	SS	MS	F	$F_{.05}$
Total	179	14,873			
Rep	5	1,913	382	6.7*	2.21
TrT	29	4,688	161	2.83*	1.46
N	2	1,939	969	16.99*	3.0
P	4	578	144	2.53	2.37
K	1	14	14	0.25	3.84
NxP	8	1,095	136	2.39	1.94
NxK	2	105	52	0.93	3.0
PxK	4	154	38	0.68	2.37
NxPxK	8	801	100	1.76	1.94
Error	145	8,272	57		

TABLE XIV

INTERACTION OF NITROGEN x PHOSPHORUS WITH OR WITHOUT POTASSIUM ON THE BRANCH NUMBER OF HETIZ JAPANESE HOLLY AFTER ONE GROWING SEASON

Without K		kg/m^3	Nitrogen Levels 1 0.0	Nitrogen Levels 2 0.417	Nitrogen Levels 3 0.833
Phosphorus Level	1	0.0	21.1_{a_1}[z][y]	$24.8_{a_{1,2}}$	29.4_{b_1}
	2	0.07	29.0_{b_2}	20.3_{a_1}	26.4_{a_1}
	3	0.15	19.9_{a_1}	$30.9_{b_{2,3}}$	28.5_{b_1}
	4	0.23	$22.2_{a_{1,2}}$	34.4_{b_3}	33.5_{b_1}
	5	0.39	$24.9_{a_{1,2}}$	32.3_{b_3}	30.0_{ab_1}

With K		kg/m^3	Nitrogen Levels 1 0.0	Nitrogen Levels 2 0.417	Nitrogen Levels 3 0.833
Phosphorus Level	1	0.0	20.7_{a_1}	21.6_{ab_1}	30.4_{b_1}
	2	0.07	21.6_{a_1}	$32.3_{b_{2,3}}$	30.9_{b_1}
	3	0.15	20.8_{a_1}	$32.6_{b_{2,3}}$	33.0_{b_1}
	4	0.23	24.1_{a_1}	40.4_{b_3}	26.3_{a_1}
	5	0.39	24.1_{a_1}	$28.8_{a_{1,2}}$	28.8_{a_1}

[z]Means in a row followed by the same letter are not significantly different at the .05% level.

[y]Means in a column followed by the same number are not significantly different at the .05% level.

Number of branches after one growing season were higher with the addition of nitrogen to the propagation medium (Table XV). As with mojave pyracantha, the addition of nitrogen also increased root weight of hetzi japanese holly after one growing season (Table XV).

TABLE XV

EFFECT OF NITROGEN ON ROOT WEIGHT AND BRANCH NUMBER OF HETZI JAPANESE HOLLY AFTER ONE GROWING SEASON

	Nitrogen Levels kg/m^3		
	1	2	3
	0.0	0.42	0.83
Root Weight (g)	47.2_a [z]	61.5_b	62.4_b
Branch Number	22.8_a	29.8_b	29.7_b

[z]Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

Experiment Two

Production Phase

Root weight of winter honeysuckle peaked at the third level of phosphorus P_3 (Table XVI). This may be due to the more rapid absorption and growth of the softwood cutting following rooting as compared to the hardwood cuttings of mojave pyracantha and hetzi japanese holly.

TABLE XVI

EFFECTS OF PHOSPHORUS ON ROOT WEIGHT OF WINTER HONEYSUCKLE AFTER ONE GROWING SEASON

	Phosphorus Levels kg/m^3		
	1 0.0	2 0.07	3 0.15
Root Weight (g)	53.7_a [z]	52.4_a	61.4_b

[z]Means in a row followed by the same letter are not significantly different at the .05% level using a protected LSD.

Comparison of Treatments vs. Controls

Dunnets test was used to compare the treatments with a predetermined standard.

Experiment One

Propagation Phase. Both 18-2.64-10 at 2.4 kg/m^3 (4 lbs/yd^3), and 27-5.28-0 at 1.5 kg/m^3 (2.5 lbs/yd^3) were equally effective as any treatment in improving visual root grade of mojave pyracantha (Table XVII). Visual root grade of hetzi japanese holly were greater for several treatments than either 18-2.64-10 or 27-5.28-0 controls (Table XVIII).

Production Phase. Osmocote 27-5.28-0 at 1.5 kg/m^3 (2.5 lbs/yd^3) was as good or better than any treatment on top weight, height, and stem caliper of mojave pyracantha (Table XVII). Treatment 2-3-2 was significantly better than 27-5.28-0 on root weight of mojave pyracantha (Table XVII).

TABLE XVII

COMPARISON OF TREATMENT VS. CONTROL OF MOJAVE PYRACANTHA

	Control Mean	Treatment Code	Treatment Mean
Visual Root Grade After Propagation			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	4.7_z		NS_y
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	6.0		NS
Top Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	265	$2\text{-}3\text{-}2_x$	326.6
Dunnets value = 54.3		2-3-1	340.9
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	319		NS
Height After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	89.5	3-5-2	97.3
		3-3-1	98.4
Dunnets value = 7.4		1-3-2	98.7
		3-4-2	98.8
		1-2-2	98.9
		3-1-2	99.6
		2-4-1	101.0
		1-4-2	104.0
		2-3-1	105.6
		2-3-2	106.9
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	100.7		NS
Stem Caliper After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	1.2	2-3-1	1.4
		2-3-2	1.4
Dunnets value = 0.12		3-2-1	1.4
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	1.4		NS

TABLE XVII (Continued)

	Control Mean	Treatment Code	Treatment Mean
Root Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	117.7		NS
27-2.58-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	100.4	2-3-2	136.4
Dunnets value = 20.7			

[z]Values are means of six observations.

[y]Treatments significantly better at the .05% level.

[x]Treatment code: Left digit = N levels 1, 2, 3; Center digit = P levels 1, 2, 3, 4, 5; Right digit = K levels 1, 2. See Table I for rates.

TABLE XVIII

COMPARISON OF TREATMENT VS. CONTROL OF HETZI JAPANESE HOLLY

	Control Mean	Treatment Code	Treatment Mean
Visual Root Grade After Propagation			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	4.2[z]	2-3-2	5.0
		2-3-1[x]	5.1[y]
Dunnets value = 0.72		2-4-2	5.1
		2-5-1	5.1
		3-1-1	5.2
		3-2-2	5.3
		2-4-1	5.4
		3-1-2	5.6
		3-4-1	5.6
		2-2-2	6.0
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	4.3	2-3-1	5.1
		2-4-2	5.1
Dunnets value = 0.72		2-5-1	5.1
		3-1-1	5.2
		3-2-2	5.3
		2-4-1	5.4
		3-1-2	5.6
		3-4-1	5.6
		2-2-2	6.0
Top Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	82.0		NS
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	62.4	3-2-2	73.6
		2-5-1	74.4
Dunnets value = 10.7		2-4-1	75.5
		2-2-2	76.0
		3-4-1	78.5
		2-4-2	79.0
Root Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	71.7		NS
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	57.5	2-4-1	73.2
		2-2-2	73.5
Dunnets value = 14.8		3-4-1	76.1

TABLE XVIII (Continued)

	Control Mean	Treatment Code	Treatment Mean
Branch Number After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	32.3	2-4-2	40.4
Dunnets value = 5.4			
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	28.0	3-4-1	33.5
		2-4-1	34.4
Dunnets value = 5.4		2-4-2	40.4

[z]Values are means of six observations.

[y]Treatments significantly better at the .05% level.

[x]Treatment code: Left digit = N levels 1, 2, 3; Center digit = P levels 1, 2, 3, 4, 5; Right digit = K levels 1, 2. See Table I for rates.

Plant response to 18-2.64-10 was as good or better than any treatment except 2-3-2 and 2-3-1 on top weight of mojave pyracantha (Table XVII). Treatments 2-3-1 and 2-3-2, along with 3-2-1 were again significantly better than the 18-2.64-10 control for height on mojave pyracantha; while on root weight, 18-2.64-10 was as good or better than all the treatments (Table XVII).

No treatments were better than 18-2.64-10 in stimulating the top weight and root weight of hetzi japanese holly (Table XVIII). Treatment 2-4-2 was better than 18-2.64-10 on branch number of hetzi japanese holly. Several treatments were better than 27-5.28-0 on top weight, root weight, and branch number of hetzi japanese holly (Table XVIII).

Experiment Two

Propagation Phase. Visual root grades of 19 treatments were significantly better than 18-2.64-10 at the 2.4 kg/m^3 (4 lbs/yd^3) rate on winter honeysuckle; while increasing the rate of the 18-2.64-10 control to 4.8 kg/m^3 (8 lbs/yd^3) showed no treatments superior (Table XIX). Many treatments were better than the 27-5.28-0 control at both the 1.5 kg/m^3 (2.5 lbs/yd^3), and 3.0 kg/m^3 (5.0 lbs/yd^3) rates on visual root grade of winter honeysuckle (Table XIX). The 13-5.72-11 at the 6.5 kg/m^3 (11 lbs/yd^3) rate was slightly better than at the 3.0 kg/m^3 (5 lbs/yd^3) level for visual root grade of winter honeysuckle (Table XIX).

Production Phase. Top weight of winter honeysuckle increased as the rate of 18-2.64-10 increased from 2.4 kg/m^3 (4 lbs/yd^3) to 4.8 kg/m^3 (8 lbs/yd^3) (Table XIX). A similar top weight increase resulted from

TABLE XIX

COMPARISON OF TREATMENT VS. CONTROL OF WINTER HONEYSUCKLE

	Control Mean	Treatment Code	Treatment Mean
Visual Root Grade After Propagation			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	3.8[z]	3-4-2	5.4
		1-5-2[x]	5.5[y]
Dunnets value = 1.5		1-3-1	5.9
		1-2-1	5.9
		3-4-1	6.2
		3-1-1	6.3
		2-1-1	6.3
		1-5-1	6.3
		1-2-2	6.4
		3-3-1	6.4
		2-4-2	6.5
		2-3-2	6.5
		2-5-2	6.8
		3-3-2	6.8
		2-2-2	7.2
		2-5-1	7.3
		3-2-1	7.6
		2-3-1	7.9
		2-1-2	8.2
18-2.64-10 @ 4.8 kg/m^3 (8 lbs/yd^3)	7.1		NS
27-5.28-0 @ 1.5 kg/m^3 (2.5 lbs/yd^3)	4.4	3-4-1	6.2
		3-1-1	6.3
Dunnets value = 1.5		2-1-1	6.3
		1-5-1	6.3
		1-2-2	6.4
		3-3-1	6.4
		2-4-2	6.5
		2-3-2	6.5
		2-5-2	6.8
		3-3-2	6.8
		2-2-2	7.2
		2-5-1	7.3
		3-2-1	7.6
		2-3-1	7.9
		2-1-2	8.2

TABLE XIX (Continued)

	Control Mean	Treatment Code	Treatment Mean
Visual Root Grade After Propagation (Cont.)			
27-5.28-0 @ 3.0 kg/m^3 (5 lbs/yd^3)	4.9	2-4-2	6.5
		2-3-2	6.5
Dunnets value = 1.5		2-5-2	6.8
		3-3-2	6.8
		2-2-2	7.2
		2-5-1	7.3
		3-2-1	7.6
		2-3-1	7.9
		2-1-2	8.2
13-5.72-11 @ 3.0 kg/m^3 (5 lbs/yd^3)	5.2	2-5-2	6.8
		3-3-2	6.8
Dunnets value = 1.5		2-2-2	7.2
		2-5-1	7.3
		3-2-1	7.6
		2-3-1	7.9
		2-1-2	8.2
13-5.72-11 @ 6.5 kg/m^3 (11 lbs/yd^3)	5.7	2-5-1	7.3
		3-2-1	7.6
Dunnets value = 1.5		2-3-1	7.9
		2-1-2	8.2
Top Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	14.0	2-1-2	17.0
		3-2-2	18.1
Dunnets value = 2.65		3-1-2	18.6
		3-3-2	18.9
		2-3-2	20.5
18-2.64-10 @ 4.8 kg/m^3 (8 lbs/yd^3)	19.8		NS
13-5.72-11 @ 3.0 kg/m^3 (5 lbs/yd^3)	15.5	3-2-2	18.1
		3-1-2	18.6
Dunnets value = 2.65		3-3-2	18.9
		2-3-2	20.5
13-5.72-11 @ 6.5 kg/m^3 (11 lbs/yd^3)	18.2		NS

TABLE XIX (Continued)

	Control Mean	Treatment Code	Treatment Mean
Root Weight After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	42.2	3-1-2	51.1
		3-2-2	51.1
Dunnets value = 5.8		2-2-2	53.7
		2-1-2	56.2
		2-3-2	58.7
		3-3-2	64.0
18-2.64-10 @ 4.8 kg/m^3 (8 lbs/yd^3)	53.8	3-3-2	64.0
13-5.72-11 @ 3.0 kg/m^3 (5 lbs/yd^3)	46.5	2-2-2	53.7
		2-1-2	56.2
Dunnets value = 5.8		2-3-2	58.7
		3-3-2	64.0
13-5.72-11 @ 6.5 kg/m^3 (11 lbs/yd^3)	54.5	3-3-2	64.0
Dunnets value = 5.8			
Branch Number After One Growing Season			
18-2.64-10 @ 2.4 kg/m^3 (4 lbs/yd^3)	4.7		NS
18-2.64-10 @ 4.8 (8 lbs/yd^3)		3-2-2	5.2
		2-2-2	5.4
Dunnets value = 1.13		3-3-2	5.5
		2-3-2	5.6
		3-1-2	5.8
13-5.72-11 @ 3.0 kg/m^3 (5 lbs/yd^3)	4.0	3-2-2	5.2
		2-2-2	5.4
Dunnets value = 1.13		3-3-2	5.5
		2-3-2	5.6
		3-1-2	5.8
13-5.72-11 @ 6.5 kg/m^3 (11 lbs/yd^3)	4.9		NS

[y]Values are means of six observations.

[z]Treatments significantly better at the .05% level.

[x]Treatment code: Left digit = N levels 2, 3; Center digit = P levels 1, 2, 3; Right digit = K level 2. See Table II for rates.

the 13-5.72-11 (Table XIX). Root weight and branch number both increased by raising the rate of 13-5.72-11 from 3.0 kg/m^3 (5 lbs/yd^3) to 6.5 kg/m^3 (11 lbs/yd^3) (Table XIX).

Several treatments were better than 18-2.64-10 at the 2.4 kg/m^3 (4 lbs/yd^3) rate; while at the 4.8 kg/m^3 (8 lbs/yd^3) rate, no treatments were better than the control on root weight (Table XIX). Branch count showed just the opposite results; as increasing the rate restricted the number of branches (Table XIX).

With all three species, treatments 2-3-2, 2-4-2, 3-2-2, and 3-3-2 were consistently better than the controls. The superior treatments all contained either the medium or high levels of nitrogen, and or phosphorus.

In general, the 18-2.64-10 control performed as well or better than the treatments. The greater growth response observed in the second experiment from increasing the rate of 18-2.64-10 from 2.4 kg/m^3 (4 lbs/yd^3) to 4.8 kg/m^3 (8 lbs/yd^3) suggests that the higher rate is superior. Nichols (24) used 1.8 kg/m^3 (3 lbs/yd^3) and 3.6 kg/m^3 (6 lbs/yd^3) osmocote 18-6-12 in his study, and suggested that greater growth may be achieved if 18-6-12 was increased from 4.8 kg/m^3 (8 lbs/yd^3) to 6.0 kg/m^3 (10 lbs/yd^3).

Pyracantha, however, responded more favorably to 27-5.28-0. This may be explained by the more rapid growth rate of pyracantha, therefore the need for more nitrogen.

CHAPTER V

CONCLUSIONS

The objective of this study was to determine the effects of slow-release nitrogen, phosphorus, and potassium fertilizers incorporated into the propagation medium, on the rooting and subsequent growth of three woody ornamentals.

Potassium was beneficial to the growth of ornamental shrubs from cuttings. With a low level of potassium, less phosphorus was needed for optimum growth. There seems to be a harmony between the three elements as they interact with each other.

Osmocote 18-2.64-10 was better than most treatments on hetzi japanese holly and winter honeysuckle. Greater growth, however, could probably be reached by increasing the rates to 4.8 to 7.1 kg/m^3 (8 to 12 lbs/yd^3). With rapidly growing species such as pyracantha, the need for the higher rate becomes more effective.

This study supports the 3-1-2 slow-release N-P-K ratio currently being used for the propagation of woody shrubs.

LITERATURE CITED

1. Babcock, F. E. 1983. The effects of nitrogen, phosphorus and potassium on the growth and performance of tree seedlings. M.S. thesis, Oklahoma State Univ., Stillwater, OK.

2. Blazich, F. A. and R. D. Wright. 1979. Non-mobilization of nutrients during rooting of Ilex crenata thunb. cv. Convexa stem cuttings. Hort. Science, 14(3):242.

3. Carney, M. and C. E. Whitcomb. 1983. Effects of two slow-release fertilizers on the propagation and subsequent growth of three woody plants. J. Environ. Hort., 1(3):55-58.

4. Chadwick, L. D. 1933. Studies in plant propagation. Cornell Agric. Expt. Sta. Bul. 571:43.

5. Choong, I. L. 1969. The relationship between rooting cofactors of easy and difficult-to-root cuttings of three clones of Rhododendron. Proc. Int. Plant Prop. Soc., 19:391-397.

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

7. 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. OK Agr. Exp. Sta. Res. Rep. P-818:21-22.

8. Girouard, R. M. 1967. Anatomy of adventitious root formation in stem cuttings. Proc. Int. Plant Prop. Soc., 17:289-302.

9. Glenn, R. C., C. Hogan and C. E. Whitcomb. 1975. Effects of osmocote in the rooting medium and auxin levels in rooting and subsequent growth of cuttings. OK Agr. Exp. Sta. Res. Rep. P-724:43-45.

10. Gouin, F. B. 1974. Osmocote in the propagation house. Proc. Inc. Plant Prop. Soc., 24:337-341.

11. Hartmann, J. J. and D. E. Kester. 1975. Plant Propagation: Principles and Practices. 3rd ed., Englewood Cliffs, NJ: Prentice-Hall, pp. 25, 211-215, 239.

12. Hess, C. E. 1965. Phenolic compounds as stimulators of root initiation. Plant physiol., 40(Suppl.):45.

13. Hess, C. E. 1962. A physiological analysis of root initiation in easy and difficult-to-root cuttings. Proc. 16th Int. Hort. Cong., pp. 375-381.

14. Hess. C. E. 1962. Characterization of the rooting cofactors extracted from Hendera helix L. and Hibiscus rose-sinensis L. Proc. 16th Int. Hort. Cong., pp. 382-388.

15. Hickman, G. G. 1983. Effects of date, nutrition and media on the vegetative propagation and growth of five selections of lace-bark elm, Ulmus parvifolia. M.S. thesis, Oklahoma State Univ., Stillwater, OK.

16. Hitchcock, A. E. 1928. Effect of peat moss and sand on rooting responses of cuttings. The Botanical Gazette, 86:121-148.

17. 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(3):320-322.

18. Johnson, C. R. and J. T. Midcap. 1979. How to handle woody stem cuttings. Am. Nurs., 11:9, 64.

19. Klingaman, G. L. and J. B. Steele. 1983. The effect of stock plant nutrition on root quality of Ilex crenata 'Convexa'. The Plant Propagator, 28(4):10.

20. Komissaron, D. A. 1968. Biological Basis for the Propagation of Woody Plants by Cuttings. Israel Program for Scientific Translations. Ltd., Jerusalem, pp. 57-89.

21. Kraus, E. J. and H. R. Kraybill. 1918. Vegetation and reproduction with special reference to the tomato. Ore. Agr. Exp. Sta. Bul. 149:1-90.

22. 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.

23. McGuire, J. J. and V. J. Bunce. 1970. The use of slow-release fertilizers in a propagation medium. The Plant Propagator, 16(2):10-14.

24. Nichols, C. L. 1982. Effects of osmocote, dolomite and micromax during propagation on the subsequent growth of four ornamental species. M.S. thesis, Oklahoma State Univ., Stillwater, OK.

25. Patel, S. I. and W. A. Grammel, Sr. 1976. The media and asexual (vegetative) propagation of Ficus benjamina L. Proc. 21st Annual Nursery Res. Conf. Rep., pp. 108-111.

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

27. Rauch, F. D. 1972. Influence of rooting medium on rooting cuttings of easy-to-root plants. The Plant Propagator, 18(2):4-7.

28. Roberts, A. N. 1969. Timing in cutting propagation as related to developmental physiology. Proc. Int. Plant Prop. Soc., 19:77-82.

29. Schulte, J. R. and C. E. Whitcomb. 1973. Effects of slow-release fertilizer in the rooting medium on rooting of cuttings and subsequent growth response. OK Ag. Exp. Sta. Res. Rep., P-691:28-31.

30. Simpson, B. J. and B. W. Hipp. 1982. Influence of nitrogen on rooting of Leucophyllum candidum cuttings. The Plant Propagator, 27(40):10.

31. Sorenson, 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.

32. Stoltz, L. P. 1968. Factors influencing root initiation in an easy- and difficult-to-root chrysanthemum. Proc. Amer. Soc. Hort. Sci., 92:622-626.

33. Threadgill, C. C. 1983. The effects of propagation container depth, diameter and media on the growth of four woody ornamentals. M.S. thesis, Oklahoma State Univ., Stillwater, OK.

34. Tukey, H. B. and H. B. Tukey, Jr. 1959. Practical implications of nutrient losses from plant foliage by leaching. Proc. Amer. Soc. Hort. Sci., 74:671-676.

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

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

37. Whitcomb, C. E., J. Gibson, and A. Sotrjohann. 1978. A comparison of three osmocote formulations and two rooting and growing media on liner quality. OK Ag. Exp. Sta. Res. Rep., P-760: 54-56.

38. Whitcomb, C. E. 1978. Propagating woody plants from cuttings. OK Ag. Exp. Sta. Bull., P-733:2.

39. Whitcomb, C. E. and D. Richards. 1979. Effects of nutrition during propagation and date of planting-out on quality of nursery stock. OK Ag. Exp. Sta. Res. Rep., P-791:36-39.

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

41. 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.

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