EVALUATION OF BIORATIONAL PESTICIDES FOR USE IN ARBORICULTURE[1]

by David G. Nielsen

Abstract. Pest control in urban and community forests is undergoing rapid change in Canada and The United States of America. Anyone who has been involved in pest control during the past 20 years realizes that the rules for pesticide use and their availability have been and are changing. Improved ability to detect minute amounts of pesticide residue, environmental awareness and activism, and increased demand for higher quality landscapes require creativity in terms of pest control approaches and products. Impending legislation and changing consumer attitudes mandate reduction in use of conventional pesticides in landscape maintenance. Biorational insecticides and acaricides, including horticultural oils, insecticidal soaps, bacterial preparations, and entomogeneous nematodes are under increasing development and are being used more widely in arboriculture. Results of investigations with some of these biorational products against important pests of trees and shrubs are reported.

Résumé. Le contrôle antiparasitaire dans les forêts urbains change rapidement au Canada et aux Etats-Unis. Quiconque a été implique dans le contrôle antiparasitaire dans les derniers 20 ans réalise que les règles d'utilisation des pesticides et leur disponibilité ont changé et changent encore. La capacité améliorée de détecter des taux résiduels de pesticides, la conscientisation et l'implication environnementale et une demande grandissante pour des aménagements paysagers de haute qualité requièrent de la créativité dans les approches et les produits de contrôle antiparasitaire. Une législation plus féroce et les attitudes changeantes des consommateurs imposent une réduction de l'utilisation des pesticides conventionnels dans l'entretien des aménagements. Des insecticides et des acaricides biorationnels, incluant les huiles, sel savons insecticides, les préparations bactériologiques et des nématodes se développant dans les insectes sont en développement croissant et sont utilisés plus largement en arboriculture. Les résultats de recherches avec quelques-uns des produits biorationnels contre des parasites importants des arbres et des arbustes sont présentés.

Urban tree pest management is undergoing rapid change in Canada and the United States of America in response to demands for better landscape quality and issues of pesticide exposure/risk. Many consumers and some arborists are no longer willing to use scheduled cover sprays on a preventive basis in an effort to keep landscape plants free of pest organisms. Furthermore, there is growing realization that pesticide management, including spraying only when and where necessary, eliminates the need for scheduled, preventive spraying. Integrated pest management (IPM) as part of plant health care provides a framework whereby practitioners monitor landscapes, use pesticides only where and when they are needed, and actually improve pest control while dramatically reducing the amount of pesticides used. This process is proving successful for those willing to learn new technology.

Another aspect of IPM that is receiving increased interest, both in terms of research and use by arborists, is the group of pest control products known as **biorationals** or *biologically rational pest control materials*. This paper presents information on selected biorational insect and mite control products, provides data on their relative effectiveness against selected pests in our research program, and suggests opportunities for increasing their usage in urban forest pest management.

Materials and Methods

Candidate products, including BT-Pyrenone, a preparation of *Bacillus thuringiensis* Burlinger (Bt) plus Pyrenone (natural pyrethrum), insecticidal soaps (salts of fatty acids), superior horticultural oil (Scalecide and Sunspray 6E), and Margosan-O (extract of the Neem tree), were evaluated under field or greenhouse conditions against selected arthropod pests of landscape trees and shrubs. Methods varied with the target pest.

Pine needle scale. Scots pine *(Pinus sylvestris)* (1.5-3 m tall) growing in Christmas tree plantations infested with a pine needle scale *(Chionaspis pinifoliae)* were used for evaluating efficacy of products against scale crawlers and settled first stage nymphs. Treatments (Table 1) were applied 6 May 1986, 21 July 1987, or 18 May 1988 to coincide with the end of crawler hatch. A KWH backpack mistblower operating at half-throttle on aperature setting 3 was used to deliver enough

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finished spray to thoroughly wet the foliage. Conditions on spray days were 24°C with 16-32 kph winds ('86), 34°C with a 6-16 kph breeze ('87), and 13°C with 16-25 kph winds ('88). Sky conditions varied from cloudy in 1986 to sunny in 1987 and overcast with threat of rain in 1988. In all years, treatments were applied to 4 single-tree replicates. No rainfall occurred for at least 24 hr in 1986 and '87; light rain (less than 0.25 cm) fell 2 hr after sprays had dried in 1988. Treatment effectiveness was evaluated ca. 2 weeks after application by removing five needle fascicles from at least three locations within each sprayed tree. Needles were placed in coin envelopes and transported in a cooler to the laboratory where percent mortality was assessed with the aid of a dissecting scope. Viability of the first 20 nymphs encountered on each of 5 fascicles was determined.

Pine tortoise scale. Scots pine (1-2 m tall) growing in Christmas tree plantations infested with pine tortoise scale *(Toumeyella parvicornis)* were used for evaluating efficacy of insecticides against mature scales. In 1985, sprays were applied 26 March when only mature female scales were present. A CO_2 compression sprayer at 40 psi with a single TeeJet SS8004 flat-fan nozzle was used to deliver sprays to run-off on four single-tree replicates. Temperature was 7-10°C with winds of 16-23 kph. Treatment effectiveness was evaluated 9 April by removing three infested twigs from each tree and evaluating mortality using a dissecting scope. In 1986, a similar, infested plantation of Scots pine was sprayed, this time with a KWH backpack mistblower operating at aperature setting 4 and spraying to runoff. Sprays were applied to three single-tree replicates per treatment on 25 April. Conditions while spraying were sunny, 23-25°C, with winds of 16-23 kph. Treatment effectiveness against mature female scales was evaluated 9 May in the aforementioned manner. In 1986, residual impact of treatments on crawler establishment was evaluated 23 June by removing five needle fascicles near the twigs infested with mature scales from each tree and counting the number of settled first nymphs with the aid of a dissecting scope.

Birch aphid. Japanese white birch *(Betula platyphylla japonica* (5.5 m tall) growing in an experimental birch plantation at The Ohio State University, Ohio Agricultural Research and Development Center near Wooster, were chosen for evaluating efficacy of dormant sprays against newly hatched nymphs of birch aphid *Euceraphis betulae).* A CO_2 compression sprayer at 40 psi with a single TeeJet SS8004 flat-fan nozzle was used to apply ca. 300 ml of finished spray to an infested branch of four, single-tree replicates per treatment. Application was made 12 April under sunny skies at 18°C and a breeze of 8-16 kph. Treatment effectiveness was evaluated 15 April by counting the number of live nymphs on 12.5 cm sections of three terminal twigs for each replicate.

Spruce spider mite. Fraser fir *(Abies fraseri)* (0.5-1.5 m tall), growing in Christmas tree plantations, were used to evaluate pesticides against spruce spider mite *(Oligonychus ununguis)* in 1987 and '88. Four heavily infested single-tree replicates were sprayed to runoff with each treatment, using a KWH backpack mistblower at half-throttle and aperature setting 3. The first application in 1987 was made 14 July under partly cloudy skies at 21°C with a 16-25 kph breeze. Trees receiving two applications were sprayed again on 24 July under sunny skies at 26°C with a 0-10 kph breeze. Treatment effectiveness was evaluated 1 week after the second application by removing four, 10-15 cm long, lateral branch tips

Table 1. Efficacy of insecticides against pine needle scale crawlers and settled nymphs in Central Ohio.

Pesticide and lb or % AI/100 gal () = g AI/l		*Mean percent mortality Days posttreatment* 7 1986	14 1987	14 1988
Dursban 4 E	1.0 (1.2)	40 b	—	87 b
Orthene 75 SP	0.5 (0.6)	21 cd	31 d	—
Sevin 80 S	1.0 (1.2)	34 bc	—	91 b
Safer Soap	2%	97 a	95 a	99 a
Murphy Soap	1%	—	52 c	—
Murphy Soap	2%	—	84 b	—
Sunspray 6 E	2%	92 a	—	—
Pestroy 8 E	1.0 (1.2)	—	98 a	—
Water Check	—	25 bcd	16 e	14 c

Means in a column followed by the same letter are not significantly different, Duncan's New Multiple Range Test (DNMRT) ($P = 0.05$). Data were transformed to arcsin $\sqrt{X}$ before ANOVA.

from each of the trees. Plant material was placed in plastic bags and transported in an ice chest to the laboratory. Samples were then processed immediately by passing twigs through a mite brush six times to dislodge mites to a rotating glass plate coated with Tween-20. Living mites were counted with the aid of a dissecting scope. In 1988, the first application was made to all treatments, except Margosan-O, on 6 June under sunny skies at 29°C with a breeze of 8-16 kph. Margosan-O was applied 15 June when second applications were made for other treatments. Conditions were sunny at 31 °C and no breeze. Treatment effects were evaluated 2, 4, and 6 weeks after the second application by removing five twigs from each tree and processing them as above.

Eastern tent caterpillar and fall webworm. Flowering fruit and shade trees growing at the OARDC and infested with fall webworm *(Hyphantria cunea)* were used to evaluate efficacy of selected insecticides against caterpillars up to 25 mm (1 inch) long. A KWH backpack mistblower operating at half-throttle and aperature setting 3 was used to spray the web and surrounding foliage in each of three single-tree replicates per treatment. Application was made 19 August 1987 under sunny skies at 22°C and no breeze. Treatment effectiveness was evaluated 5, 8, and 14 days posttreatment by visually examining nests and assessing larval mortality. The same procedures were used to evaluate candidate insecticides against eastern tent caterpillar *(Malacosoma americana)* infesting chokecherry *(Prunus virginiana)* growing along roadsides in Wayne County, Ohio, in 1988. Application was made 11 May under sunny skies at 16°C with a 24-32 kph wind. Efficacy was determined as above.

Gypsy moth. Containerized northern red oak *(Quercus rubra)* seedlings (1-0) growing in a greenhouse were sprayed to run-off with a CO_2 compression sprayer with a SS-8804 flat-fan nozzle at 20 psi. In 1986, plants were sprayed before 4th instars were placed on seedlings. In 1987, five 4th instars were placed on plants prior to application. Forty-eight hours later, an additional five larvae were placed on each treated plant. Following application, larvae were constrained by securing a 1 gallon Fonda carton around the seedling in each container. The top of the carton was replaced with nylon organdy for ventilation. Larvae and foliage were observed daily until final mortality counts were made 72 ('86) or 96 h after application or placing larvae on treated foliage.

Japanese beetle. Pyracantha *(Pyracantha angustifolia)* 'Gnome' (0.2 m tall) growing in containers were used to evaluate efficacy of insecticides against Japanese beetle *(Popillia japonica* Newman) adults. A CO_2 compression sprayer with a TeeJet SS-8004 flat-fan nozzle was used to apply foliar and topical sprays to runoff. Foliar applications were made at 40 psi on 24 July under sunny skies at 29°C and a 16-25 kph breeze. Treatments received ca. 0.8 cm of rainfall 4 hours after sprays were applied and 2.0 cm additional rainfall throughout the test period, along with 3.8 cm of weekly overhead irrigation after first samples were removed. Foliar sprays were evaluated by removing two 10-15 cm twigs from each plant at specified intervals. They and 5 field-collected beetles were placed in 1-liter Fonda cups with mesh tops. Residual efficacy of insecticides was evaluated 1, 3, 7, 14, and 21 days after foliar sprays were applied by allowing adults to feed on sprayed foliage for 48 h. After 48 h, moribund adults were placed on unsprayed foliage, and final percent mortality was assessed 48 h later. Topical applications were made at 15 psi on 27 July under sunny skies at 27°C and an 8-16 kph breeze. In topical tests, three 10-15 cm twigs were placed upright in culture tubes with the cut end in water. Five adults were placed on each twig, and sprays were applied to runoff in the aforementioned manner. Adults and twigs were immediately transferred to 1-liter Fonda cups fitted with mesh tops. Treatment effectiveness was evaluated as above. All treatments were replicated 3 times.

Data were analyzed by analysis of variance. Treatment means were separated using Duncan's new multiple range test (Duncan 1955).

Results and Discussion

Pine needle scale. Safer insecticidal soap caused high mortality of settled nymphs in all three years of evaluation, and was consistently more effective than standard, conventional products. Murphy's insecticidal soap at the 1% rate was more effective than Orthene in 1987 and provided relatively good control at the standard rate of 2% (Table 1).

Results from three years of testing indicate that insecticidal soaps are excellent products for controlling crawlers and settled first stage nymphs of pine needle scale. Our results suggest that their timing may be less important than with conventional products. However, applicators should always apply these and other pesticidal substances when target insects are in their most vulnerable stage. Sprays for armored scale insects, like pine needle scale, Euonymus scale *(Unaspis euonymi)*, and oystershell scale *(Lepidosaphes ulmi)*, should always be applied soon after crawler hatch has ended but before they molt to the second stage. If crawler hatch extends beyond about 5 days in the South or 7 to 8 days in the North, two applications at 5 to 10 day intervals may be required to achieve an acceptable level of control.

Horticultural oils, sometimes in combination with a conventional insecticide like Ethion, have been used for control of scale insects for decades. In our 1986 trial, 2% horticultural oil (Sunspray 6E) was as effective as insecticidal soap and better than the standards Dursban, Orthene, and Sevin (Table 1). Baxendale and Johnson (1) used Sunspray 6E at 3% against soft and armored scales, both after crawler hatch was advanced and just as or before hatching commenced. In all trials, the treatment caused excellent control of crawlers and settled first stage nymphs; unhatched eggs were killed as the oil penetrated beneath the protective covering secreted by the female scale. Since insect metabolism is extremely high during the late stages of incubation and early crawler activity, oils can be expected to be most effective at that time, if indeed their mode of action is to interfere with gas exchange. More tests are needed to evaluate effectiveness of lower concentrations of horticultural oils to determine their minimum dosage and the window of opportunity against both armored and soft scales.

Pine tortoise scale. None of the insecticides evaluated against overwintered females in early spring 1985 was effective, as measured by our evaluation procedures (Table 2). Application of soap and oil in late April, 1986, again failed to cause obvious mortality of overwintered females. However, later foliage sampling indicated that Sunspray 6E significantly reduced the number of first stage nymphs on adjoining branches after hatch was complete. This result indicates that oils may cause sublethal effects that eventually provide population reduction through means other than direct toxicity to sprayed life stages. Tests by Baxendale and Johnson (1) would seem to substantiate this speculation.

Birch aphid. Even high concentrations of insecticidal soap and horticultural oil, used alone, failed to signficantly reduce aphid numbers on branches of white birch soon after overwintered eggs had hatched in 1985 (Table 3). However, a combina-

Table 2. Efficacy of insecticides against pine tortoise scale in Ohio.

Pesticide and lb or % AI/100 gal	*Mean percent mortality[a]*		*Mean no. live crawlers[b]*
() = g AI/l	*1985*	*1986*	*1986*
Safer Soap 4%	*0*	-	-
Scalecide 2 & 4%	*0*	-	-
Safer + Scalecide 2 + 2%	*0*	-	-
Safer Soap 2%	*0*	*39 b*	*5 ab*
Sunspray 6 E 2%	-	*37 b*	*4 b*
Orthene 75 SP 0.75 (0.9)	-	*41 b*	*7 ab*
Supracide 2 E 1.0 (1.2)	*0*	-	-
Trimethacarb 3.3 F	-	*100 a*	*0 c*
Water check	*0*	*8 b*	*18 a*

Means in a column followed by the same letter are not signficantly different, DNMRT (P = 0.05).
[a] Data were transformed to arcsin x before ANOVA.
[b] Data were transformed to log_{10} (X + 1) before ANOVA.

Table 3. Efficacy of insecticides against a birch aphid in Ohio.

Pesticide and lb or % AI/100 gal () = g AI/l	*Mean number live nymphs*
Safer Soap 4%	42 ab
Safer Soap 10%	27 ab
Scalecide 2%	41 ab
Scalecide 4%	22 abc
Safer + Scalecide 4 + 2%	18 bc
Turcam 76 WP 1.0 (1.2)	0.2 c
Water Check	46 a

Means in a column followed by the same letter are not signficantly different, DNMRT (P = 0.05). Data were transformed to log_{10} (x + 1) before ANOVA.

tion of Safer soap and Scalecide caused a signficant reduction in aphid numbers. Since this test was performed on branches, rather than entire trees, it is possible that within-tree migration of wingless aphids during the 3 days from application to sampling resulted in a conservative estimate of treatment effects. This work needs to be repeated by spraying entire, isolated trees with each product. Furthermore, it appears that combinations of soaps and oils deserve further evaluation as aphicides. Since aphids and resultant honeydew are common problems in environmentally sensitive areas, including patios, swimming pools, and ponds, these biorational products need to be tested in novel ways to maximize their utility in landscape management.

Spruce spider mite. The mite population diminished naturally soon after the second application in 1987, even on the unsprayed check plants, precluding critical evaluation of treatment effects. However, the limited data obtained indicated that pesticidal soaps can not be expected to provide control of spruce spider mite unless at least two applications are used (Table 4). Although a single application of Plictran was effective, it has been removed from the market and is no longer available to landscape managers or producers of nursery crops or Christmas trees. Other conventional miticides like Kelthane also require two applications at a 6 to 10 day interval, depending upon local temperatures.

Even two applications of Safer insecticidal soap were ineffective by themselves in 1988, but the soap showed promise as an acaricide when combined with cotton seed oil (Table 4). Again, mite populations diminished soon after the 2-week sampling, precluding further evaluation of residual effectiveness of treatments. Sunspray 6E was ineffective against spruce spider mite, but should be evaluated at higher concentrations and in combination with soap and other products before it is discarded as a miticide. In a small-scale test with spruce spider mite on Hemlock *(Tsuga canadensis)*, Baxendale and Johnson (1) achieved excellent mite control with a single application of 3% Sunspray 6E. They had similar results against spider mites on deciduous landscape plants.

Defoliators. Soaps and oil sprayed on webs (tents) and surrounding foliage of infested trees in the field were ineffective against eastern tent caterpillar and fall webworm (Table 5). However, when soaps were applied topically to 4th instar gypsy moth on containerized oaks in the greenhouse, they provided acceptable larval mortality (Table 6). In the same test, when larvae were placed on foliage previously treated with soap, the treatment was ineffective. This indicates that if soaps are to be effective against lepidopterous defoliators, application should be made when larvae are small and before webs provide significant protection from contact sprays. Since there is no residual effectiveness, even when larvae eat treated foliage (see Table 6), thorough coverage of all plant surfaces is critical to efficacy.

Similar results were obtained with soaps against Japanese beetle adults. When foliage was sprayed before beetles were placed on plants, soaps were ineffective. However, in 1988 and 1989, when the beetles were contacted with Safer insecticidal soap, all of them died within 24 hours. If thorough coverage can be achieved and repeated applications are feasible, it appears that

Table 4. Efficacy of insecticides against spruce spider mite in Ohio.

Pesticide and lb or % AI/100 gal () = g AI/l	*Number applications*	*Mean no. mites 1987*	*Mean no. mites 1988*
Safer Soap 2%	*1*	*2 ab*	—
Safer Soap 2%	*2*	*0 b*	*5.3 abc*
Safer Soap + SSI	*2*	—	*11.3 a*
Safer Soap + CSO	*2*	—	*0.8 bc*
SS + SSI + CSO	*2*	—	*0.8 bc*
SSI .05%	*2*	—	*9.8 a*
CSO .25%	*2*	—	*10 a*
Murphy Soap 1%	*2*	*0 b*	—
Murphy Soap 2%	*1*	*6 a*	—
Murphy Soap 2%	*2*	*0 b*	—
Margosan-O .66%	*1*	—	*9 a*
Sunspray 6 E 2%	*2*	—	*4.5 abc*
Kelthane 35 WP 0.33 (.42)	*2*	—	*0 c*
Plictran 50 WP 0.125	*1*	*0*	—
Water check (1988)	*2*	—	*3.8 abc*
Unsprayed check (1988)	—	—	*12.8 a*
Water check (1987)	*2*	*2.3 ab*	—

Means in a column followed by the same letter are not signficantly different, DNMRT (P = 0.05). Data were transformed to log_{10} (X + 1) before ANOVA.
SS = Safer insecticidal soap; SSI = water conditioner (0.48 ml/l); CSO = cotton seed oil (2.4 ml/l).

insecticidal soap is a viable treatment for controlling Japanese beetle adults in landscape management. This usage is probably more amenable to use by homeowners than arborists, since repeat applications are costly and sometimes impossible to provide to a large number of customers on a timely basis.

Sunspray 6 E was ineffective against Japanese beetles, whether applied to foliage or when sprayed directly on the adults. Margosan-O was ineffective as a foliar spray against this important pest.

The combination of natural pyrethrum and B.t. provided excellent control of 2nd instar gypsy moth within 3 days and 4th instars within 5 days (Table 6). This combination product may have utility in urban forest pest management. Natural pyrethrum, singly and in combination with biorational and conventional pesticides, deserves further attention as efforts are made to reduce usage of conventional pesticides in urban and community forests.

Conclusion

Horticultural oils and soaps have broad labels for use against insect and mite pests of woody landscape plants. None of them caused obvious phytotoxicity in tests reported here or in studies reported elsewhere (1, 2, 3). McClure (4) had good success with horticultural oil against Fletcher scale *(Parthenolecanium fletcheri)* on yews *(Taxus cuspidata* 'Densiformis' and 'Hicksii,') in the fall without causing phytotoxicity. However, when Scalecide was applied during winter, followed by subfreezing temperatures, phytotoxicity was evident on both cultivars (5).

Oils and soaps are proving effective against a number of important pests that lead to widespread, annual pesticide application in the urban forest. Although definitive recommendations for their use cannot all be based on research results at this time, arborists and other landscape managers are encouraged to try them on a limited basis in comparison to standard products. If they

Table 5. Efficacy of insecticides against defoliators in Ohio.

Pesticide and lb or % AI/100 gal () = g AI/l	*Mean percent mortality*		
	Fall webworm	*Eastern tent caterpillar*	*Japanese beetle adults*
Murphy Soap 2%	5 b	—	—
Safer Soap 2%	5 b	8 d	0 b
Safer Soap 2%	(Topical = contact)	—	100 a
Sunspray 6E 2%	—	27 c	0 b
Sunspray 6E 2%	(Topical = contact)	—	7 b
Margosan—O 0.66%	—	—	0 b
Sevin SL 1.0 (1.2)	98 a	80 b	100 a
Tempo 2 0.02 (.028)	—	100 a	100 a
Water check	5 b	8 d	7 b

Means in a column followed by the same letter are not significantly different, DNMRT (P = 0.05). Data were transformed to arcsin $\sqrt{x}$ before ANOVA.

Table 6. Efficacy of insecticides against gypsy moth larvae under greenhouse conditions.

Pesticide and lb AI/100 gal or %	*Mean percent mortality*						
	Days after treatment						*On 48 h residues*
	1		*3*		*5*		
	2nd	*4th*	*2nd*	*4th*	*2nd*	*4th*	
Bt-Pyrenone WP (.5 f.)	0	053	27	100	87		—
Bt-Pyrenone WP (1.0 f.)	20	0	93	40	100	100	—
Sevin 80 S 1.0	100	100	—	—	—	—	—
Water check	0	0	0	0	0	0	—
Murphy Soap 2%	—	27a	—	—	—	67b	0
Safer Soap 2%	—	13a	—	—	—	87ab	0
Orthene 75 SP 0.25	—	27a	—	—	—	100a	100
Water check 0	—	0a	—	—	—	0c	

Means within a column below the line followed by the same letter are not signficantly different (P = 0.05), DNMRT. Data were transformed to arcsin $\sqrt{x}$ before ANOVA.
f. = formulation

prove effective, then biorational products can be used on a larger scale to reduce non-target impacts of landscape pest control.

Arboriculture, by definition, concerns environmental enhancement through professional management of our tree and shrub resources. Surely, arborists agree that this must be done without degrading other components of the environment. Biorational pesticides can help us achieve these goals and are worthy of increased usage by arborists. Their development deserves major effort by agricultural pesticide companies and renewed research efforts by scientists at Land Grant institutions.

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ABSTRACTS

WEBSTER, A. 1988. **Coming of age.** Am. Nurseryman 168(10):107-109.

Twenty years ago, people only called on consulting arborists when they wanted to know why their trees died. But now, with America's emphasis on preventive tree care, nurserymen and consumers are demanding—and getting—more from specialists. That's where consulting arborists come in. They're the specialists in preventive tree care. This profession has been emerging for more than two decades. Thanks to America's new awareness of trees and nurserymen's increased exposure to liability, it has now reached maturity. Consulting arboriculture requires knowledge beyond that needed by many practicing arborists, getting into physiology, pathology and entomology. As specialists, consulting arborists have expertise in the health requirements and monetary value of trees, as well as species selection for various growing conditions.

GOOD, G.L. 1989. **Fertilizing shade trees.** Landscape Contractors, May, pp. 20-21.

Research during the last 10 to 15 years has resulted in signficant modifications or alternatives to traditional approaches that will result in more efficient and effective N-P-K fertilization of shade trees. Most significantly, research has demonstrated the effectiveness of nutrients, particularly nitrogen, applied to the soil surface over the root systems of shade trees. Trials have indicated that surface placement of N-P-K fertilizers is as good as, or better than, subsurface applications. Trees absorb nutrients applied to the soil surface because the nutrients move downward with water that percolates through the soil, and because tree roots near the soil surface can absorb the migrating nutrients.