FUNDAMENTAL RESEARCH ON THE EFFECTS OF ANTIFREEZE AGENTS ON ROADSIDE ENVIRONMENTS

Masataka Nakada* and Takao Nakaya**

*Director, Road Department, Construction Bureau, Sendai Municipality
3-1-1 Kokubun-cho, Aoba-ku, Sendai, Miyagi, 980-0803, Japan
Tel:+81-22-214-8381/Fax:+81-22-227-2614
E-Mail: masataka_nakada@city.sendai.jp

**Tohoku Branch Office, Central Consultant Inc.
27-21 Tachimachi, Aoba-ku, Sendai, Miyagi, 980-0822, Japan
Tel:+81-22-264-1924/Fax:+81-22-264-1217
E-Mail: tnakaya@central-con.co.jp

1. Abstract

In the 1980s in Sendai City, road dust generated by the studded tires of vehicles was often spread around the city by the wind in early spring, and a phenomenon dubbed the “Sendai Desert” badly affected the daily civic life there, becoming a serious social problem. Under these circumstances, the Sendai Municipality has been spreading antifreeze agent on the major roads since 1983, as one of the measures to support “movements against studded tires.” Meanwhile, the Municipality has been carrying out fundamental environmental impact assessments and collection of the necessary data for the last 18 years, in order to monitor existence of the negative secondary effects of antifreeze agent on roads.

Generally, antifreeze agent blown by the winter wind and splashed up by passing vehicles is concentrated within three meters of the edge of a carriageway. Thus, in order to grasp the effects of the antifreeze agent on roadside trees, as an experiment, visual inspection of trees as well as measurement of the ingredients of antifreeze agent contained in the branches and leaves of trees and the adjacent soil have been carried out, and an outline of the results is the province of this paper.

There were two types of trace effects from the antifreeze agent on roadside trees: (1) splashed antifreeze agent directly adhering to roadside trees, and its elements then permeating into the trees through stomata and gaps in the bark, and (2) splashed antifreeze agent first permeating and accumulating in the soil of a planted area, and then its elements being taken into the trees through the roots as they absorbed nourishment and moisture. However, stronger effects were observed in case (1), and interim conclusions have been reached on items such as the possibility of visual identification, the significant effect on the shrub genus, the varying effects by type of tree, and the limited effects on the large tree genus due to lesser adhesion of the antifreeze agent.

In case (2), among the elements of antifreeze agent in the soil of a planted area of roadside trees, it is supposed that calcium decomposes, leaving limited remnants in the soil. On the other hand, a concern is that sodium and chlorine ions may not decompose, and remain in soil close to the surface.

However, many cases were observed in which the effects of antifreeze agent on roadside trees were considered to be due to excess absorption of the elements of antifreeze agent splashed on and adhering to the trees.

2. Background of the Research

The number of registered vehicles in Sendai City has rapidly increased since the 1980's due to the high rate of population increase, because Sendai City has been functioning as the political and economical center of the Tohoku region. As a result, road dust, generated from the abrasion of asphalt pavement by studded vehicle tires utilized during the winter season (December to March), spread all over the city, causing a phenomenon dubbed the "Sendai Desert." Under these circumstances, people living along roads grew anxious about their health, and the phenomenon became a serious social problem—a form of urban pollution. Thus, both metropolitan officials and the citizenry introduced movements against studded tires.

In order to cope with the situation, the Sendai Municipality started to implement various measures to support the movements against studded tires. From the perspective of securing safety for road traffic during the winter season, therefore, key road maintenance measures were introduced, such as lowering the minimum level of snow on roads that triggered removal work from 15cm to 3cm, establishment of a 24-hour snow removal and melting work schedule, and spreading of antifreeze agent on major roads, etc.

3. Objectives of the Research

The Sendai Municipality has been spreading antifreeze agent on major roads since 1983. Meanwhile, the Municipality has been carrying out fundamental environmental impact assessments with various observations of roads spread with antifreeze agent and laboratory experiments, as well as collection of the necessary data, for the last 18 years, in order to monitor existence of the negative secondary effects of antifreeze agent on roads, with the advice and cooperation of experts from various academic and professional fields.

This paper, then, presents an outline of the results of the observation of the vigor of roadside trees, by visual inspection and laboratory examinations of the branches and leaves of those trees and soils in planted areas, in the context of results of various observations and experiments on the effects of the use of antifreeze agents on roads.

4. Contents of the Observation

In Sendai City, from the perspective of preventing freezing of the road surface and securing safety for road traffic during the winter season, a solution of calcium chloride (35% concentration) has been spread on roads mainly in hilly and mountainous terrain since 1983, and a mixed solution (urea (35% concentration) 65% and sodium chloride (23% concentration) 35%) in flat terrain since 1993. This results in antifreeze agent blown by the winter wind and splashed up by passing vehicles being generally concentrated within three meters of the edge of the carriageway, though the situation varies by weather and road surface condition.

As a result, there is a possibility that roadside trees close to the carriageway may be affected when splashed antifreeze agent directly adheres on their branches and leaves.

There is another possibility that soil in areas planted with roadside trees may affect roadside trees, because elements of antifreeze agent can permeate and accumulate in the soil. To delineate changes and differences in the above factors in recent years (1994-2000), visual inspection of trees to observe the extent of the effects has first been conducted. Then, the quantity of antifreeze agent elements absorbed in the branches and leaves of roadside trees, and the quantity of antifreeze agent elements that have accumulated in the soil in areas planted with roadside trees have been measured during the winter season, in experiments to grasp the cause of the effects.

4.1 Visual Inspection of the Vigor of Roadside Trees

(1) Outline of the Inspection

Visual inspections of roadside trees have been carried out for four periods, namely the new growth period (May), the deciduous period (November), the period after spreading of antifreeze agent (March), and the next year's new growth period (May).

Types of roadside trees selected for visual inspection were: 1) tall deciduous trees, i.e., zelkava serrata (elm genus), acer buergerianum (maple tree genus), and liriodendrou tulipifera (magnolia genus), 2) evergreen shrubs, i.e., buxus microphylla var. insularis (boxtree genus), ligustrum Japonicum (fragrant olive genus), and quercus phillyraeoides (beech genus), and 3) deciduous shrubs, i.e., enkianthus perulatus (azalea genus).

(2) Results of Inspection

a) The effects of antifreeze agent on tall deciduous trees were comparatively small. Weakness in these trees were mainly due to their planting environment (weather conditions, inadequately sized soil plots, increased exhaust emissions due to an increased number of vehicles, etc.) and maintenance/care for the trees (particularly applying water and pruning).

b) For evergreen shrubs, discoloration of leaves and fallen leaves were observed for many types of trees after the spreading of antifreeze agent. Particularly along curved sections of trunk roads, downhill sections where vehicles travel at relatively high speeds, and sections with many ruts, where elements of melted antifreeze agent easily remain, the effects of antifreeze agent were clearly observed: lower twigs facing the carriageway were withered and the vigor of the shrubs was weakened.

c) For deciduous shrubs, it was impossible to observe the condition of leaves, because leaves had fallen before the spreading of antifreeze agent. However, the effects of antifreeze agent were clearly observed: twigs facing the carriageway were withered and new growth was also weak in the new growth period.

4.2 Examination of Branches and Leaves of Roadside Trees

(1) Outline of Examination

In this examination, measurements and comparison of the content of calcium, natrium, and chlorine ions, which are elements of antifreeze agent, have been carried out using two samples of each tree type. Those samples were obtained from roadside trees planted adjacent to the carriageway, which were considered directly affected by the spreading of antifreeze agent, and the same type of roadside trees planted far from the carriageway, which were considered unaffected by splashed antifreeze agent and thus in the same situation as roadside trees along carriageways where antifreeze agent was not spread (control sample for purposes of comparison).

Sampled trees were selected from the locations at which the visual inspections for vigor were carried out, and branches of tall deciduous trees as well as twigs and leaves of evergreen and deciduous shrubs were collected.

(2) Results of the Examination

The following characteristics were obtained for branches/twigs and leaves of roadside trees, by focusing on types and parts of trees which had a higher tendency to absorb more elements of antifreeze agent compared with plants in the areas where antifreeze agent was not spread (See Figure 1):

a) For tall trees, the following absorption tendencies were identified:

Higher absorption of natrium

- Branches of zelkava serratas (planted along roads where both calcium chloride and mixed agent were spread (hereinafter referred as "two type application"))
- Branches of acer buergerianums (planted along roads where only calcium chloride was spread (hereinafter referred as "calcium chloride application"))

Higher absorption of chlorine ions

- Branches of acer buergerianums (planted along roads where only mixed agent was spread (hereinafter referred as "mixed agent application"))

b) For shrubs, the following absorption tendencies were identified:

Higher absorption of calcium

- Twigs and leaves of buxus microphylla var. insularis ("calcium chloride application")
- Twigs and leaves of enkianthus perulatus ("mixed agent application")

Higher absorption of natrium

- Twigs and leaves of enkianthus perulatus ("mixed agent application")
- Twigs and leaves of quercus phillyraeoides ("mixed agent application")
- Leaves of buxus microphylla var. insularis ("calcium chloride application")
- Twigs of ligustrum Japonicum ("calcium chloride application")

Higher absorption of chlorine ions

- Twigs and leaves of quercus phillyraeoides ("mixed agent application")
- Twigs and leaves of buxus microphylla var. insularis ("calcium chloride application")
- Leaves of enkianthus perulatus ("mixed agent application")

c) By antifreeze agents elements, the following absorption tendencies were identified:

Higher absorption of calcium

- Twigs and leaves of enkianthus perulatus ("mixed agent application") as shrubs

Higher absorption of natrium

- Branches of zelkava serratas ("two type application") and acer buergerianums ("calcium chloride application") as tall trees

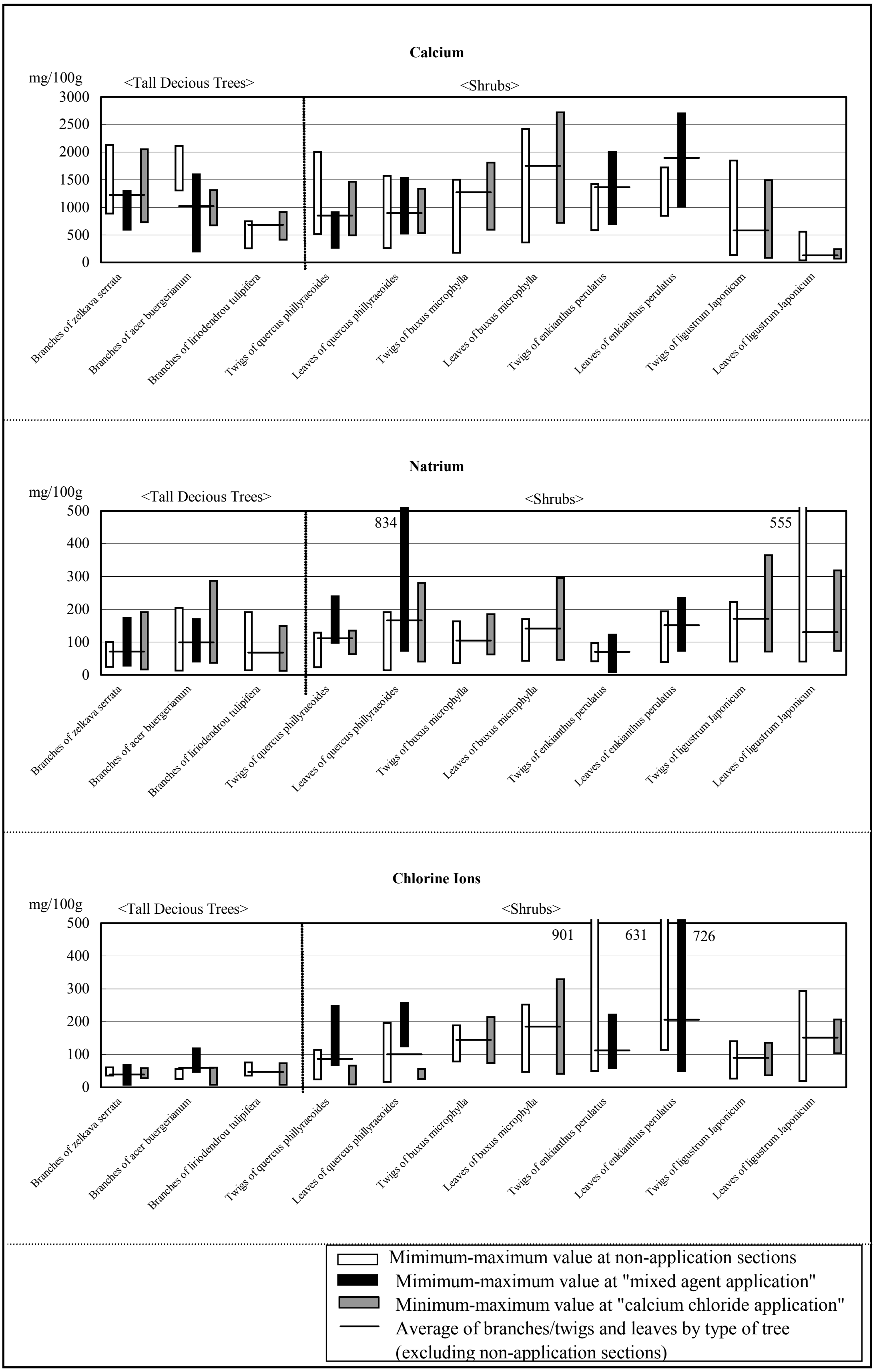

Figure 1 Absorption Tendencies of Antifreeze Agent Elements by Roadside Trees (Average Value of Samples Obtained between November 1994 and November 2000)

- Leaves of buxus microphylla var. insularis ("calcium chloride application"), twigs of ligustrum Japonicum ("calcium chloride application"), and twigs and leaves of quercus phillyraeoides ("mixed agent application") as shrubs

Higher absorption of chlorine ions

- Leaves of buxus microphylla var. insularis ("calcium chloride application") and enkianthus perulatus ("mixed agent application"), and twigs and leaves of quercus phillyraeoides ("mixed agent application") as shrubs

d) As a result of the examination, it became clear that absorption of calcium was comparatively low and that its effects on roadside trees were moderate, while absorption of natrium and chlorine ions was high, and their effects on roadside trees were conspicuous.

4.3 Examination of Soil in Planted Plots

(1) Outline of Examination

In this examination, two kinds of soil samples before (November) and after (March) spreading of antifreeze agent (November) were collected from plots planted with roadside trees, and chemical analyses of pH, electric conductivity, substituent calcium, substituent natrium, chlorine ions, and 10% KCL extracted nitrogen were carried out, in order to grasp the change of chemical composition in soils in planted plots after the spreading of antifreeze agent. Sample soils were collected from the locations where the visual inspections of tree vigor and examination of branches/twigs and leaves of roadside trees were carried out.

(2) Results of the Examination

Changes of soil content at sampled locations after spreading of antifreeze agent were as follows:

a) According to the result of this examination, remarkable quantities of substituent calcium, substituent natrium, chlorine ions, and 10% KCL extracted nitrogen were found to remain in soils from planted plots along roads where antifreeze agent was spread, compared with planted plots along roads where it was not. In addition, electric conductivity, which tends to have a high correlation with those basic groups, was drastically changed. As a result, it was judged that large quantities of antifreeze agent elements remained in the soil close to the surface (see Figure 2).

b) After spreading of antifreeze agent, chlorine ions remained in the soil along sections treated with "calcium chloride application," while substituent natrium, chlorine ions, and 10% KCL extracted nitrogen remained in the soil along sections treated with "mixed agent application" (see Figure 3).

4.4 Effects of Spreading of Antifreeze Agent on Roadside Trees

The major antifreeze agent elements spread by the Sendai Municipality are calcium, natrium, chlorine, nitrogen, etc., and these are also indispensable elements of nourishment for plants (fertilizer). Generally, positive ions, such as calcium and natrium, have strong tendencies to move into the bodies of plants, while negative ions, such as chlorine, have weaker such tendencies. [1), 2), 3)]

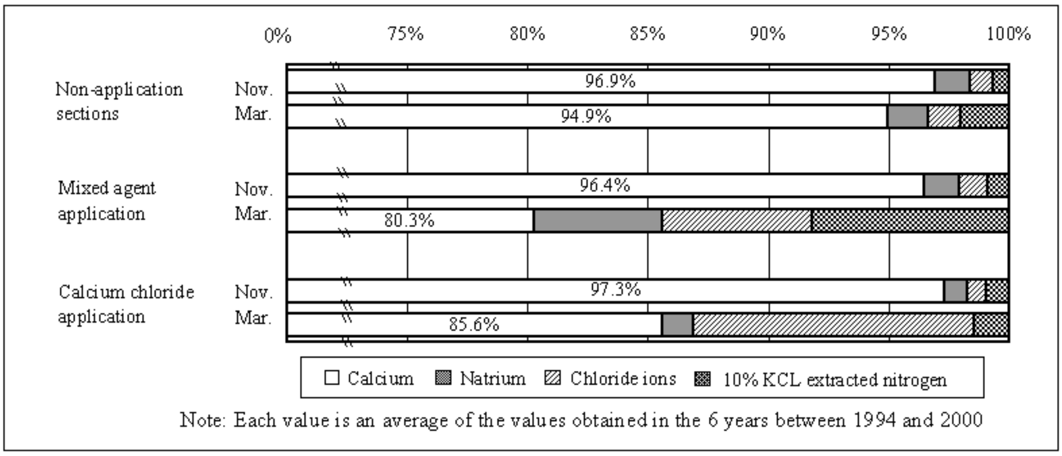

Figure 2 Major Changes in Chemical Composition of Soils before and after Spreading of Antifreeze Agent (Average Value of Samples Obtained between March 1994 and November 2000)

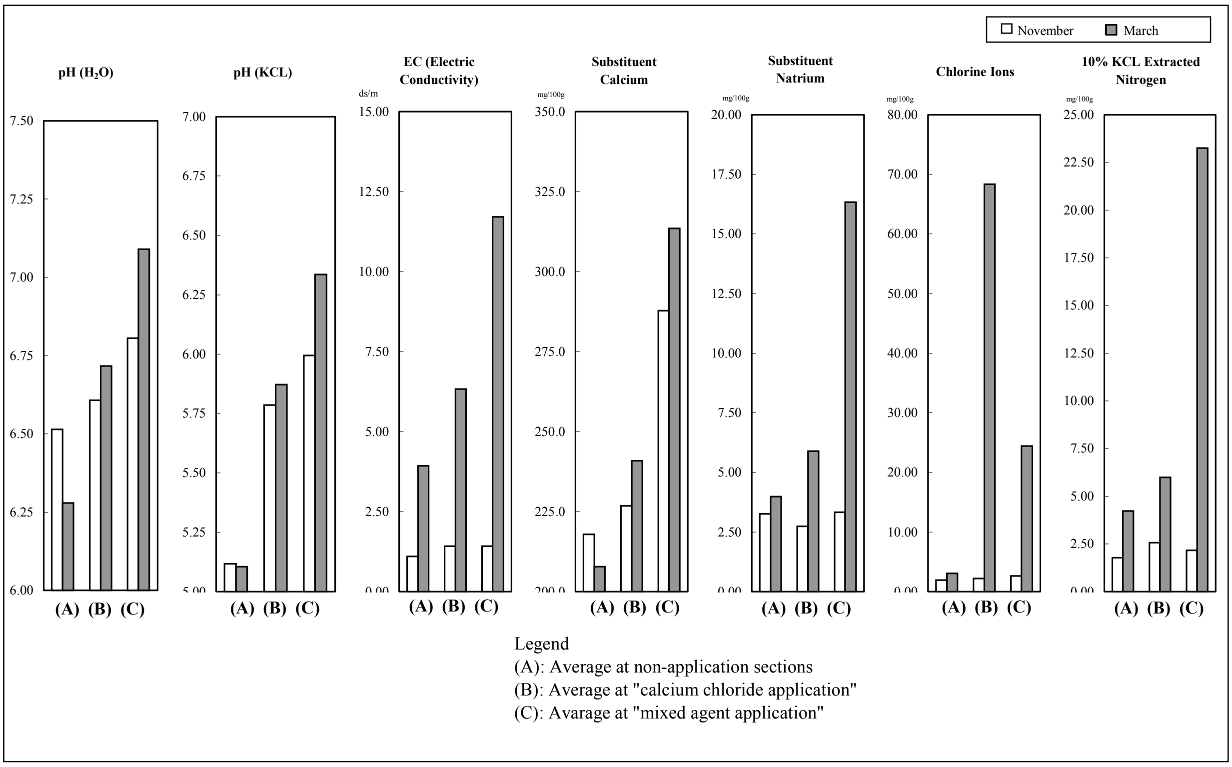

Figure 3 Major Changes in Content of Antifreeze Agent Elements in Soils from Planting Plots before and after Spreading of Antifreeze Agent, for Sections where Antifreeze Agent Was or Was Not Spread (Average Value of Samples Obtained between March 1994 and November 2000)

However, after the spreading of antifreeze agent, a very limited quantity of elements indispensable for nourishment, originally contained in the bodies of plants, will drastically increase for the time being, and nourishment in the bodies of plants may become unbalanced. Therefore, excessive absorption of these elements into plants has become a matter of concern, as a direct effect of the spreading of antifreeze agent.

(1) Changes in Branches/Twigs and Leaves of Roadside Trees

For branches/twigs and leaves of roadside trees planted along roads where antifreeze agent was spread, calcium content did not change drastically, even compared with control group plants, while content of natrium and chlorine ions drastically changed compared with the control group. As a result, the effects of antifreeze agent could be identified visually.

By tracing the possible routes that generated effects on roadside trees, the following two possibilities were hypothesized:

a) Splashed antifreeze agent directly adhering to roadside trees, and its elements then permeating into the trees through stomata and gaps in the bark.
b) Splashed antifreeze agent first permeating and accumulating in the soil of a planted area, and then its elements being taken into the trees through the roots as they absorbed nourishment and moisture.

Stronger effects were observed in case a), and visual identifications were possible, but effects were different by type of tree. Generally, the leaves of evergreen plants have developed a cuticular layer, and they tend to repel splashed antifreeze agent, and thus the level of effect is considered to be low. However, those leaves were also affected when antifreeze agent was frequently splashed, directly adhering on the leaves. Those leaves evidenced black or light brown necroses generated from the surrounding part of leaves to the whole part, with abnormal defoliation also observed (see Figure 4). As a result of this observation, it was supposed that these effects were remarkable on shrubs and that the level of effect was different by type of tree. On the other hand, effects on tall trees were considerably less, because direct adherence of splashed antifreeze agent on them was limited.

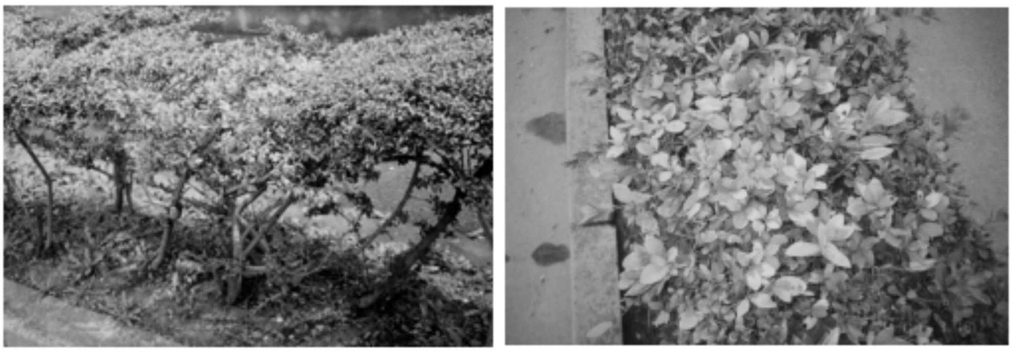

Figure 4 Example of Routes that Generated Effects on Branches/Twigs and Leaves of Roadside Trees

(2) Movement of Antifreeze Agent Elements in the Soil and Their Effects on Roadside Trees

Since antifreeze agent elements spread at low temperatures in the winter may be absorbed by trees between spring and autumn, when tree roots become active in absorbing nourishment and moisture, excessive accumulation of these elements in the soil is concerning because of their direct effects on roadside trees after spreading of antifreeze agent.

Hence, for route b), it was important to identify the movement of antifreeze agent and the quantity of it remaining in the soil of planted plots.

The results of observations showed that higher amounts of each element were measured in the following types of trees, compared with the remaining quantity of elements in the soil after spreading of antifreeze agent:

<u>For sections with "calcium chloride application"</u>

- Calcium, natrium, and chlorine ions in twigs and leaves of buxus microphylla var. insularis
- Natrium in branches of zelkava serratas, quercus phillyraeoides, and ligustrum Japonicum

<u>For sections with "mixed agent application"</u>

- Calcium and natrium in twigs and leaves of enkianthus perulatus
- Natrium and calcium in twigs and leaves of quercus phillyraeoides
- Chlorine ions in twigs of acer buergerianums

As a result, there were possibilities that shrubs were affected by elements of antifreeze agent not only by excessive absorption of elements from splashed and adhered antifreeze agent adhering to their surfaces, but also by absorbing elements from planted soils. (See Figure 5)

5. Future Tasks

Based on the results of past observations, it is considered that the following surveys might be conducted:

- Identification of types of antifreeze agents, and the quantity of each splashed and adhering to roadside trees on roads
- Identification of the relation between the quantity of antifreeze agent elements absorbed and the depth of the roots of roadside trees in the same type of tree.

At the same time, it is considered to be necessary to set up an experimental field, transplanting experimental saplings of deciduous and evergreen broadleaf trees, and carrying out the following experiments, improving the accuracy of observation and analysis:

- Spraying antifreeze agent directly on branches/twigs and leaves as well as soil under snowfall in a winter, and making observations according to the density and quantity of agents
- Comparison of branches/twigs and leaves of trees from the same type of tree planted in soil where only water is sprayed.

References:

1) "Environmental Range of Soils" (May 1997, Fuji Techno System Co., Ltd.)

2) "Report on Study of Documents related to Antifreeze Agents" (1990, Montreal University)

3) "Curtailing Usage of De-icing Agents in Winter Maintenance" (1989, OECD)

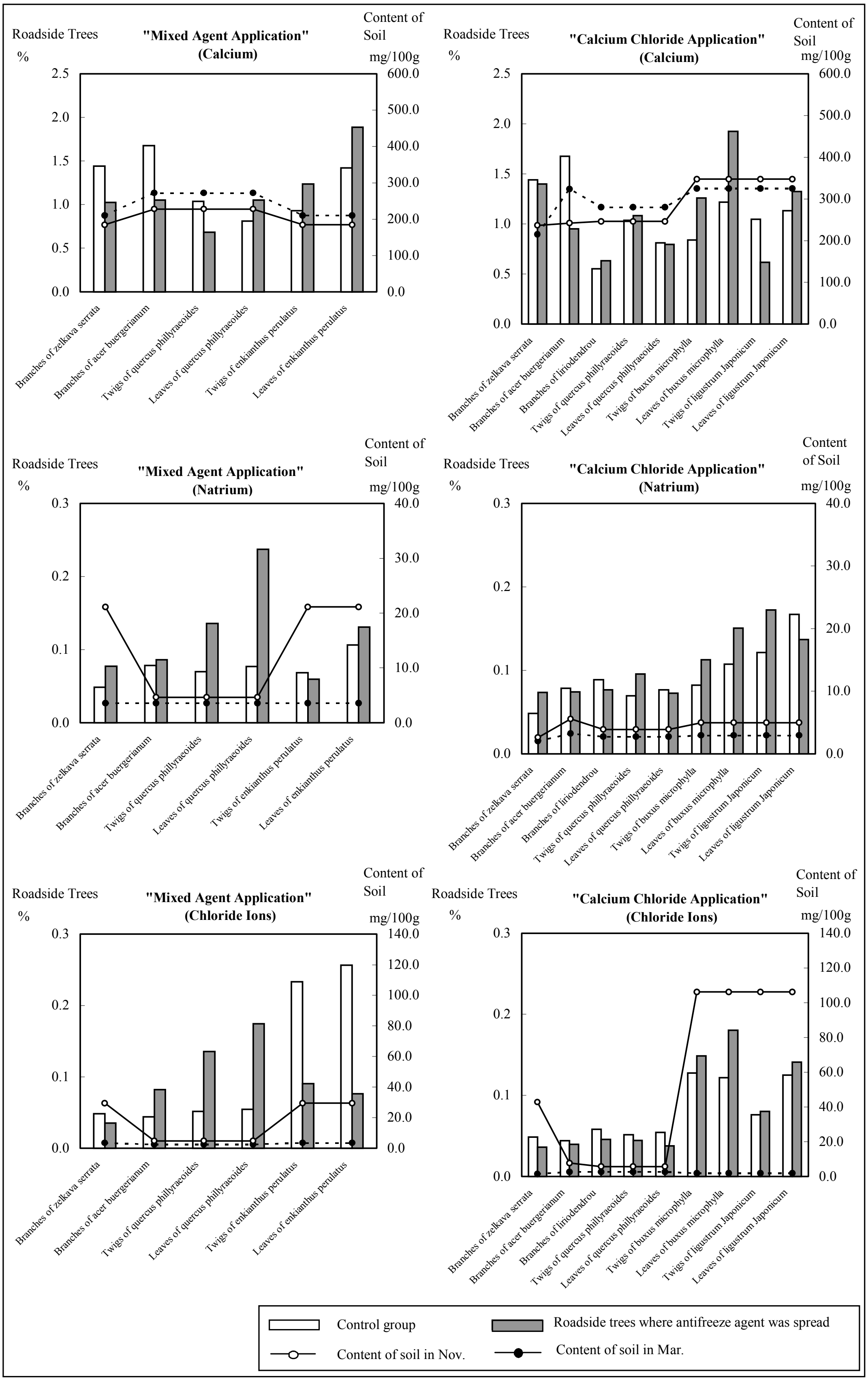

Figure 5 Relation between Content of Antifreeze Agent Elements in Branches/Twigs and Leaves of Roadside Trees and Soils in Planted Plots