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AICE SURVEY OF USSR AIR POLLUTION LITERATURE. VOLUME III. THE SUSCEPTIBILITY OR RESISTANCE TO GAS AND SMOKE OF VARIOUS ARBOREAL SPECIES GROWN UNDER DIVERSE ENVIRONMENTAL CONDITIONS IN A NUMBER OF INDUSTRIAL REGIONS OF THE SOVIET UNION

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Silver Spring, Maryland

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AICE* SURVEY OF USSR AIR POLLUTION LITERATURE

Volume III

THE SUSCEPTIBILITY OR RESISTANCE TO GAS AND SMOKE OF VARIOUS ARBOREAL SPECIES GROWN UNDER DIVERSE ENVIRONMENTAL CONDITIONS IN A NUMBER OF INDUSTRIAL REGIONS OF THE SOVIET UNION

Edited By

M. Y. Nuttonson

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A compilation of reports of investigations dealing with a number of aspects of the relationship of air pollution and vegetation. A number, of these investigations have been conducted in industrial regions that are geographically far apart from each other and subject to distinctly different natural and man-made environmental conditions. The adverse effects of air pollution on some of the indigenous and introduced plant species are described. Susceptibilities to specific phytotoxic air pollutants and injury symptoms in different species and their ecotypes are also discussed. Much attention is given to the resistance of various plants to different gases and to smoke, to some of the environmental conditions as well as to some physiological indices in relation to smoke and gas resistance of plants, and to the problem of plant selection for resistance to smoke and gas pollution.

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PREFACE

Much of the background material presented in the preface to Volume II of this series is repeated here in view of its relevance to the present volume.

Contamination of the natural environment constitutes a major problem in all industrial regions of the Union of Soviet Socialist Republics (USSR). The country's industry and transport are continually bringing about massive qualitative changes in the habitat of man and vegetation through an ever increasing pollution of air, soil, and streams. In recent years there has been a greater awareness of the immense problems of air and water pollution on the part of the urban and rural administrative agencies as well as on the part of various research institutes of the USSR. There is a mounting demand there to maintain a high quality physical environment. Protective measures against the pollution threat are gradually taking shape. Much relevant air pollution research data are being developed and are apparently put to good use in some parts of this vast and diverse country.

Reports of investigations brought together in this volume deal with a number of aspects of the relationship of air pollution and vegetation. A considerable number of these investigations have been conducted in various industrial regions of the USSR, regions that are geographically far apart from each other and subject to distinctly different natural and man-made environmental conditions.

Many of the investigations reported in this volume relate to the urban and rural areas particularly affected by air pollution and a number of these areas are situated in widely separated industrial regions, the main ones being:

The Ural Region of RSFSR
The Moscow Region of RSFSR
The Leningrad Region of RSFSR
The Belorussian SSR
The Azerbaizhan SSR
The Kazakh SSR.

The problem of selecting suitable plants for new environmental conditions -- whether natural or man-made -- has challenged man throughout the centuries of his migration. Selection of plants for introduction and establishment in a new environment may be a rather simple hit-or-miss undertaking, or it may become a painstaking process requiring a knowledge of plant responses to such potent factors of the physical environment as photoperiod, light intensity, temperature, humidity, soil moisture, and soil fertility. It is rather widely accepted now that air pollution, wherever it occurs, must be taken into account as another highly potent factor in the physical environment of plants. The nature of air pollution has to be considered in the assessment of the environmental conditions prevailing in a given area in relation to the overall problem of plant selection and plant adaptation. A plant, irrespective of its genetic potentialities and elasticity of adaptation to environmental conditions, responds to the various stresses of its environment. These include the stresses of air pollution together with all the other potent factors of the atmosphere as well as of soil and those of the biological environment of a plant, notably, pests and diseases, and the quality of management or abuse by man.

As will be seen from the data of the papers presented in this volume a considerable number of studies are being conducted in the USSR in reference to susceptibility or resistance of different plant species and their ecotypes to various phytotoxic air pollutants in different parts of the country.

It must be borne in mind that the data presented in this volume relate to many diverse environments in a vast land area; that the USSR extends for about 7,000 miles from west to east and 3,000 miles from north to south; and that the country covers a wide range of climatic and soil conditions throughout much of its north-south and west-east extent. In this connection, a brief outline of the very general natural features of the USSR may be desirable. Lowlands and plains dominate the landscape of the major portion of the country. Its landscape can be roughly described as one consisting of broad latitudinal climate-vegetation-soil belts of the lowlands and plains and of narrow, vertical climate-vegetation zones of the highlands and mountains. Each of the broad latitudinal belts is distinct from the other in the major features of its climate, vegetation, and soils, though within each latitudinal belt there is a decrease in the annual precipitation as one proceeds from west to east. The latitudinal belts include the nearly barren and treeless tundra in the extreme north, where the winters are severe, the summers, short and cool, and where precipitation is very limited. There follow the belts of the taiga or coniferous forests, mixed forests, woodlands, forest prairie or forest steppe, the steppe, and the semi-desert. Finally in the extreme south, east of Caspian Sea, there are the dry deserts, hot in summer and cold in winter, and, along the southern reaches of the Black Sea in Transcaucasia, there is a relatively limited area, humid and more or less subtropical, which is subject to mild winters, hot summers, and heavy precipitation.

A considerable number of surveys and studies presented in this volume deal with the effect of industrial atmospheric pollutants on various plant species grown in forests, in public parks, in gardens, in street plantings as well as for sanitary-protection purposes in different cities and localities at various distances from industrial developments, and situated differently in respect to their directional position from specific pollutant sources. The adverse effects of air pollution on some of the indigenous and introduced plant species -- effects often leading to complete plant destruction, such as for example, the death of ornamental plantings in urban parks and gardens and the death of forest plantings -- are described in some of the studies. Susceptibilities to specific phytotoxic air pollutants and injury symptoms in different species and their ecotypes, are also discussed.

A number of papers bring out the fact that the response to air pollution differs with the plant species as well as with the ecotypes within a species and that the growth stage of the plant, notably the age of the leaf, is an important factor in determining its sensitivity to air pollutants. Much attention is given in quite a few of the papers to the resistance of various plants to different gases and to smoke, to some of the environmental conditions as well as to some physiological indices in relation to smoke and gas resistance of plants, and to the problem of plant selection for resistance to smoke and gas pollution.

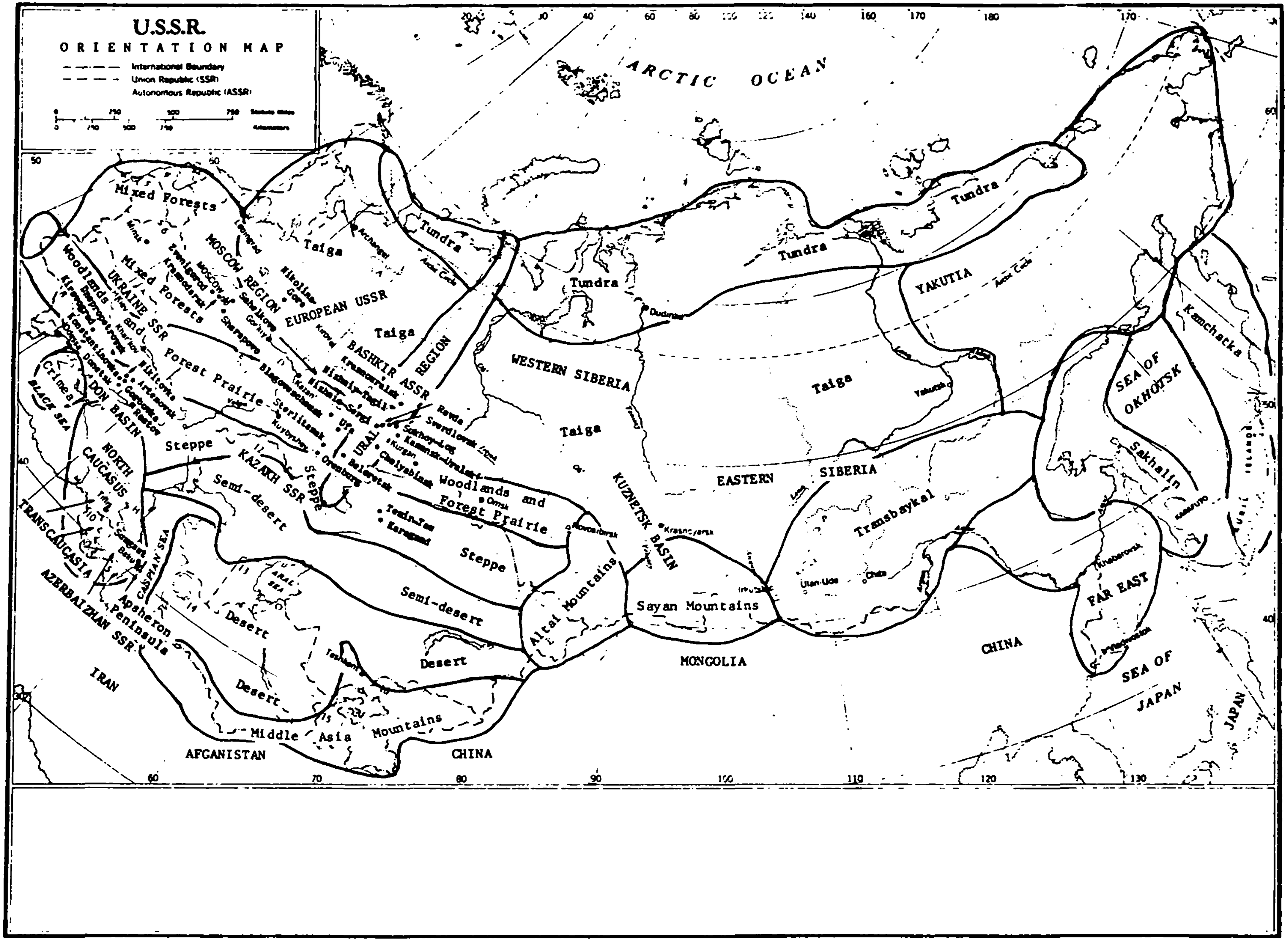
The data of several studies and surveys presented in this volume suggest that on the basis of experimental plot tests and field observations the genetic susceptibility or resistance of certain plant species and ecotypes have been determined in a number of areas. The use of the resistant plants in industrial regions as shelter belt plantings around residential areas and in urban parks, gardens, and street plantings merits consideration. The same is true (a) in reference to rural areas subject to air pollution where shelter belt plantings are used as a means of protecting farm crops, forests, and other vegetation, and (b) in reference to certain cultural practices that appear to be conducive to a lessening of plant sensitivity to phytotoxic air pollutants.

It is hoped that the papers selected for presentation in this volume will permit an assessment of some of the USSR studies dealing with the manifold interrelationships of air pollution and vegetation. There is a possibility that the usefulness of such studies would be greatly increased if supplementary detailed information could be assembled and analyzed with regard to the specific environmental conditions under which each set of the data reported were developed. Such information, properly organized and analyzed, would permit a more precise identification of specific environmental responses of a given species or ecotype or variety grown in a given area under specific pollutant and time-concentration relations. It would also permit a clearer visualization of comparable climate and soil conditions in North America. This may facilitate the verification of plant responses and plant adaptability and may also make possible the utilization of some of the USSR plant material under similar ecological conditions in North America.

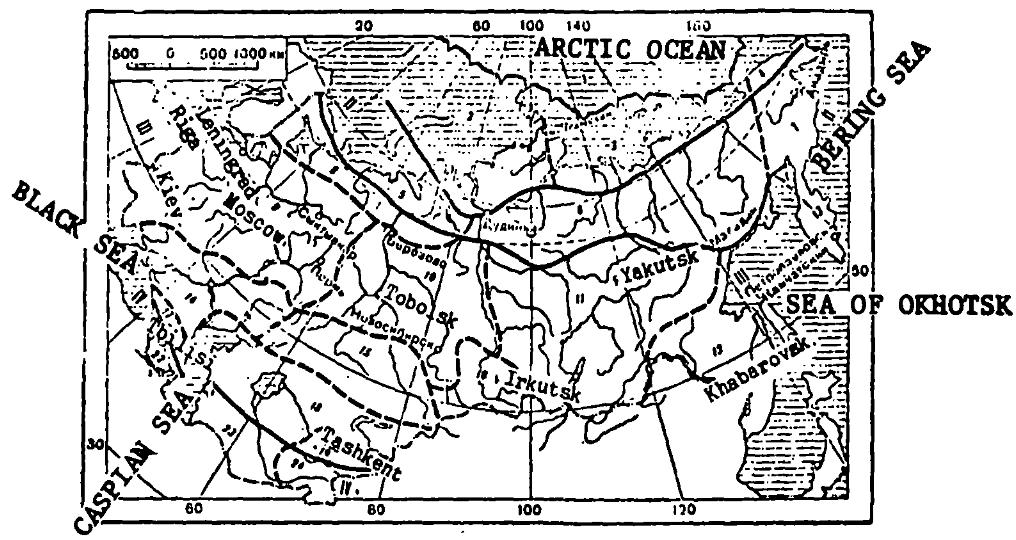
As the editor of this volume I wish to thank my co-workers in the Air Pollution Section of the Institute for their valuable assistance. Special thanks are due to Dr. M. Hoseh, who as the principal translator rendered valuable service in connection with many phases of this survey.

M. Y. Nuttonson

Silver Spring, Maryland
May 1970


U.S.S.R.
ORIENTATION MAP
International Boundary
Union Republic (SSR)
Autonomous Republic (ASSR)
ARCTIC OCEAN
Mixed Forests
Taiga
Tundra
MOSCOW REGION
EUROPEAN USSR
BASHKIR ASSR
REGION
URAL
UKRAINE SSR
Woodlands and Mixed Forests
Forest Prairie
Crimea
BLACK SEA
DON. BASIN
NORTH CAUCASUS
TRANSCAUCASIA
AZERBAIZHAN SSR
Apsheron Peninsula
CASPIAN SEA
Steppe
KAZAKH SSR
Semi-desert
Desert
ARAL SEA
Woodlands and Forest Prairie
WESTERN SIBERIA
KUZNETSK BASIN
Altai Mountains
Sayan Mountains
EASTERN SIBERIA
Transbaykal
YAKUTIA
Kamchatka
SEA OF OKHOTSK
Sakhalin
FAR EAST
SEA OF JAPAN
JAPAN
CHINA
MONGOLIA
IRAN
AFGANISTAN
Middle Asia Mountains

CLIMATIC ZONES AND REGIONS* OF THE USSR



Zones: I-arctic, II-subarctic, III-temperate, IV-subtropical
Regions: 1-polar, 2-Atlantic, 3-East Siberian, 4-Pacific, 5-Atlantic, 6-Siberian, 7-Pacific, 8-Atlantic-arctic, 9-Atlantic-continental forests, 10-continental forests West Siberian, 11-continental forests East Siberian, 12-monsoon forests, 13-Pacific forests, 14-Atlantic-continental steppe, 15-continental steppe West Siberian, 16-mountainous Altay and Sayan, 17-mountainous Northern Caucasus, 18-continental desert Central Asian, 19-mountainous Tyan-Shan, 20-western Transcaucasian, 21-eastern Transcaucasian, 22-mountainous Transcaucasian highlands, 23-desert south-Turanian, 24-mountainous Pamir-Alay

* After B. P. Alisov

THE EFFECT OF INDUSTRIAL GASES AND INDUSTRIAL SMOKE

ON VARIOUS FOREST SPECIES

P. S. Pogrebnyak

From P. S. Pogrebnyak. Obshchee lesovodstvo. Vtoroe izdanie. Moscow, Izdat. "Kolos", 1968, p. 215-17.

The air over large industrial centers contains gaseous and particulate matter vented by the heating units and smokestacks of industrial plants. This matter which remains suspended and does not precipitate over a long period of time, consists of sulfur oxides, nitrogen oxides, carbon monoxide, tarry substances, soot, cement dust, and the like.

Industrial exhausts are injurious to vegetation, particularly to evergreen trees and especially to conifers. Coal dust clogs the stomata and deprives them of elasticity; cement dust alkalizes the cell content of leaves and hydrolyses (eats away) their integumental tissue. Sulfur dioxide is particularly injurious to leaves; at a content of 0.00001% by volume in the air its effect is noticeable on plants. Penetrating the cells through the stomata and by osmosis through the integumental tissues of the leaves, sulfur dioxide forms strong acids, sulfurous and sulfuric, which lower the pH of the cell content to 2.0-2.5 and depress the cytoplasm*. The large scale desiccation of coniferous species in forests near industrial plants is a widespread phenomenon in Western Europe. In our country it has not attained such large proportions. However, foresters have to consider the problem of protection, prevention, and treatment of forests damaged by gases vented into the air by chemical and metallurgical plants.

Coniferous species are affected by poisonous gases more than other species. The perennial leaves of the majority of the evergreen conifers are poisoned continuously and are usually dead in the second year. The species that normally shed their leaves annually and remain bare during winter (larch, deciduous trees, and to a large extent arborvitae) get rid of the greater part of absorbed poisons. Thus, these species, being bare in winter, are capable of withstanding better the severe industrial gas pollution of the air.

The poisoning by sulfur dioxide starts with the yellowing of the leaf tips, and the appearance of reddish spots, and ends with the color change of leaves or needles to brownish red, an indication of necrosis. In the case of evergreen conifers exposed to moderate but constant poisoning, the current year needles appear normal, those of the previous year sick, and older needles fall off. Damaged trees suffer partial loss of their current year leaves along the edges of the crown, and this in turn

*[Translator's note: The Russian translates as "depress the plasm."]

causes thin foliage. The greatest damage to evergreen conifers is caused in summertime, during the period of vigorous development of the needles and of intensive photosynthesis. During winter, even large concentrations of injurious admixtures in the air do not cause noticeable damage.

Moss and lichen are among the most sensitive indicators of air pollution; they disappear even at small concentrations of sulfur dioxide in the air. Moss on old straw-thatched roofs disappears even near such small gas venters as garages and small coal-operated power plants. Recent investigations showed that spraying pine boughs, slightly damaged by sulfur dioxide, with a 2% solution of sodium carbonate containing a small quantity of permanganate restores the normal reaction of cell sap.

There are various degrees of resistance of tree species to industrial gases, as compiled by several authors (Schroder and Reuss, Stoklaza, Wislicenus, Grohman, Gerlach, and others). These standards are frequently contradictory because the observations on the basis of which they were compiled were made under differing conditions, and because in most tree species the vulnerability differs with age. Thus, a young fir is insensitive to industrial gases but after the age of 40 it becomes most sensitive, along with spruce, and Swiss stone pine. Larch and those evergreens having dove gray needles, such as Colorado spruce, Engelmann's spruce, Serbian spruce, as well as arborvitae, junipers, lodgepole pine, and false cypress, should be considered resistant and are recommended for growing under conditions of moderate air pollution. Eastern white pine is considered resistant to smoke (Cermak, 1960). The dove gray color is generally attributable to a wax deposit on the surface of the needle, the thin layer of wax protecting the leaf from the penetration of injurious gases and smoke. Very sensitive and non-resistant are spruce, fir, and yew, particularly when they grow old. Leafy species arranged according to their increasing degree of resistance are: linden, ash, beach, maple, elms, alder, poplar, birch, and oak. Of these, the last three are fully resistant and the first three are sensitive.

For conditions existing in Karaganda, the resistance arranged in decreasing order is: pinnate elm, Russian olive or oleaster, balsam poplar, box elder, Tatarian or Tartar honeysuckle, lilac, Siberian pea shrub, or peat tree, European white birch, and Scotch pine (A. S. Sitnikova, 1966). Under conditions of Azerbaidzhan, to the above should be added: pistachio, almond, willow-leaved pear, corkbark elm, and others. From this it is apparent that gas resistance is to some degree correlated with drought resistance.

It is therefore obvious that the problem of protecting forests against noxious gases primarily concerns conifers, exclusive of larch. One of the most important ways of coping with this problem is to select gas- and smoke-resistant varieties and types of woody species.

The dust concentrations of forest air is negligible. In suburban forests it amounts to 1/14th of the average dust content in the atmosphere (Neuwirth, 1965). Forests are natural filters for dust and noise.

Literature

[Translator's note: Unfortunately the author did not provide any bibliography; therefore, no sources of the references mentioned are available.]

THE INFLUENCE OF SMOKE AND GAS ON THE FLOWERING AND FRUITING OF SOME TREES AND SHRUBS

V. G. Antipov
Central Botanical Garden of the Academy of Sciences of the Belorussian SSR

From Akad. Nauk BSSR. Belorusskoe Otdelenie Vsesoyuznogo Botanicheskogo Obshchestva. Sbornik Botanicheskikh Rabot, Vyp. II, (Minsk, 1960), p. 167-172.

The question of the influence of smoke and gas discharged from industrial enterprises on the flowering and fruiting of plants has been relatively little studied. E. Haselhoff and G. Lindau (1903), according to the observations of Fr. Nobbe and A. Shtokhardt, describe the influence of coal smoke on wheat. They wrote that if the action of the smoke coincided with the time of the flowering of the wheat, then the stamens would dry up, resulting in empty or poor embryos of very light (weight) seed. The side of the spike facing the source of smoke was particularly affected. According to the observations of A. Shtokhardt, in a fruit orchard exposed to coal smoke, as early as the next day there were evident traces of damage to the leaves, and the young green fruit, especially plums, fell off.

Survey data concerning the effect of smoke on the fruiting of trees under the conditions of the Donbass were assembled by Kh. M. Isachenko (1938).

The results of a study of seeds (in accordance with G.O.S.T. 2937-47), collected on an industrial enterprise, were published by us in 1957.

During the course of two growing periods we made additional observations of the flowering and fruiting of trees and shrubs, in three different industrial chemical enterprises.

Industrial Enterprise A

From a mill, situated 50 to 75 meters from the plantings, gas was given off in an unorganized and continuous manner. The concentrations of the gases in the area of the plants were as follows (in g./m^3):

methane	-	0.01084,
ethylene	-	0.00262,
acetone	-	0.00175,
acetic acid	-	0.0011

Likewise, the plants were affected by flue smoke from a heat and electric power plant (HEP) situated 200 meters from the plantings. The concentrations of these (gas) discharges were not established. The relief of the land was uniform; the trees and shrubs were not shielded by buildings from the effect of smoke and gas.

Industrial Enterprise B

The distance from the smoke flue of HEP to the plantings ranged from 10 to 100 meters. The main pollutants were large particles of coal, carbon black, soot, and ashes. The relief of land was uniform; the plants were not protected by buildings from the effect of pollutants.

Industrial Enterprise C

From a mill, situated 75 to 100 meters from the plantings, ethyl chloride, ethylene, ethyl ether (diethyl ether), and benzene were discharged in an unorganized and continuous manner. The concentrations of ethyl chloride and ethylene in the area of the plantings were as follows ($g./m^2$):

ethyl chloride - 0.0116,

ethylene - 0.0081;

the concentrations were not determined for the rest of the gases. The relief of the land was uniform and the plants were not closed off by buildings from the effect of gas.

An assessment of the abundance of flowering and fruiting of trees and shrubs, growing in the given industrial enterprises, was done visually according to a six-degree scale:

0 - no flowers or fruit

1 - very weak flowering and fruiting

2 - weak flowering and fruiting

3 - satisfactory flowering and fruiting

4 - good flowering and fruiting

5 - abundant flowering and fruiting

The results of the investigations are presented in Table 1.

As can be seen from Table 1, out of the 25 species of trees and shrubs examined in the 3 industrial chemical enterprises, the majority was observed to have quite satisfactory flowering.

Significant quantitative decreases were observed in the flowering of common birch, penduculate oak, snowy mespilus, and cluster bird cherry.

Table 1

Species	Industrial Enterprise A Flower	A Fruit	B Flower	B Fruit	C Flower	C Fruit	Notes
1	2	3	4	5	6	7	8
Siberian pea tree Caragana arborescens L.	-	-	4	2	0	0	
European barberry Berberis vulgaris Lam.	5	5	-	-	-	-	
White birch Betula pubescens Ehrh.	-	-	2	1	3	1	Catkin seriously diminished
European white birch Betula verrucosa Ehrh.	0	0	1	0	-	-	Majority of the fruit fell off prematurely
Common English hawthorn Crataegus oxyacantha L.	5	5	5	5	-	-	
Red-berried elder Sambucus racemosa L.	-	-	4	4	-	-	
Russian elm Ulmus laevis Pall.	0	0	2	0	-	-	
Tartar dogwood Cornus alba L.	4	1	-	-	-	-	
Pedunculate oak Quercus robur L.	0	0	0	0	1	0	Fruit clung for some time, but fell prematurely
Tartar honeysuckle Lonicera tatarica L.	5	5	-	-	2	0	
Garden serviceberry Amelanchier rotundifolia (Lam.) Dum.-Cours.	-	-	-	-	1	0	
Hedge cotoneaster Cotoneaster lucida Schlecht.	-	-	-	-	3	2	
Norway maple Acer platanoides L.	4	3	-	-	-	-	
Small-leaved linden Tilia cordata Mill.	0	0	-	-	3	1	
Speckled alder Alnus incana (L.) Moench.	4	3	-	-	3	2	Cones of small dimensions
Japanese rose Rosa rugosa Thumb.	2	0	-	-	-	-	
Mountain ash Sorbus aucuparia L.	-	-	4	4	-	-	
Urals false spirea Sorbaria sorbifolia (L.) A. Br.	-	-	-	-	5	0	
Black currant Ribes nigrum L.	-	-	3	0	-	-	
Balsam poplar Populus balsamifera L.	-	-	0	0	0	0	
Mongolian poplar Populus suaveolens Fisch.	-	-	3	1	-	-	
Aspen Populus tremula L.	3	0	4	2	4	1	Fruit clung for some time, but fell prematurely
Cluster bird cherry Padus racemosa (Lam.) Gilib.	0	0	-	-	1	0	
Sweet mock orange Philadephus coronarius L.	3	2	-	-	-	-	
European ash Fraxinus excelsior L.	-	-	2	1	0	0	

Note: Dashes indicate absence of the given species on the grounds of the enterprise.

In the Siberian pea shrub and common ash, the usual flowering was absent in Enterprise C only, while in the Russian elm and small-leaved lime, flowering was absent in Enterprise A only. Among all the examples complete absence of flowering in all enterprises occurred only with the balsam poplar.

Gas and smoke exhibited a stronger influence on the fruiting of trees and shrubs than on flowering. Under the given conditions, for a number of species, flowering might be observed but not setting of the fruit as for example in the case of the Japanese rose and the trembling poplar, in Enterprise A; as well as in the case of the Russian elm and the black currant in Enterprise B; and in the case of the round-leaved serviceberry, the Urals false spirea, and the cluster bird cherry in Enterprise C. In the other species fruit setting took place but the fruit fell unripened (white birch, common birch, pedunculate oak and Mongolian poplar).

The following species showed satisfactory fruiting under the given conditions: European barberry, common hawthorne, red berry elder, ledge cotoneaster, Norway maple, speckled alder, mountain ash, and sweet mock orange.

There was a significant decrease of fruit in the following species: Tartar dogwood, small-leaved lime, Mongolian poplar and the common ash.

In the white birch, this diminishing was expressed in the number of female flower clusters, as well as in their dimensions while in the speckled alder, the decrease was basically in the dimensions of the female flower cluster (Figure 1). Its male catkins had normal dimensions.

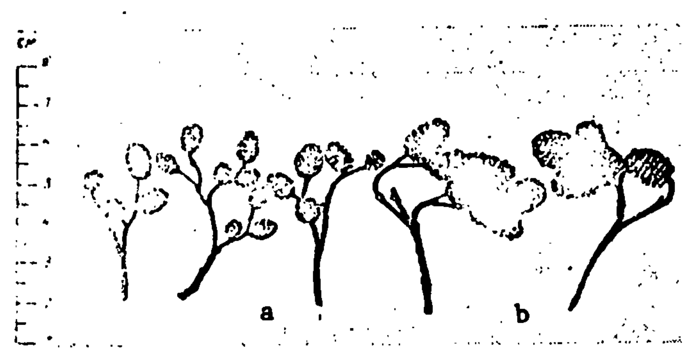


Fig. 1: Speckled alder (Alnus incana (L.) Moench.)

a - Ripe cones with fruit (in Enterprises A and C) which developed under the influence of smoke and gas.

b - Control

Fruiting was completely absent on all enterprises in the case of the birch, Russian elm, pedunculate oak, round-leaved serviceberry, Japanese rose, Urals false spirea, black currant, balsam poplar, and the cluster bird cherry.

Better flowering and fruiting of trees and shrubs was observed in the enterprises where the basic air pollutants were not gases but carbon black, ashes, and soot. In these enterprises, supplementary observations on the flowering and fruiting of shrubs were made. For this survey 50 flowers (more or less, depending on availability) were recorded from various parts of the crown of each shrub. The resulting observations are given in Table 2.

Table 2

Variety	Industrial Enterprise	Lower layer of crown						Upper layer of crown					
		Side						Side					
		Southern			Northern			Southern			Northern		
		Quantity of flowers	Green fruit	Ripe fruit	Quantity of flowers	Green fruit	Ripe fruit	Quantity of flowers	Green fruit	Ripe fruit	Quantity of flowers	Green fruit	Ripe fruit
European barberry <u>Berberis</u> <u>vulgaris</u> L.	A	-	-	-	12	5	2	15	-	-	50	21	16
Common English hawthorn <u>Crataegus</u> <u>oxyacantha</u>"L.	A	50	17	13	50	15	13	50	26	18	50	23	19
Red berry elder <u>Sambucus</u> <u>racemosa</u> L.	B	50	19	17	50	12	11	50	22	18	50	23	21
Tartar dogwood <u>Cornus</u> <u>alba</u> L.	A	50	6	5	50	4	4	50	18	-	50	7	2
Tartar honeysuckle <u>Lonicera</u> <u>tatarica</u> L.	A	12	2	-	50	17	12	-	-	-	50	19	14
Garden serviceberry <u>Amelanchier</u> <u>rotundofolia</u> (Lam.) Dum.-Cours.	C	-	-	-	-	-	-	15	-	-	12	-	-
Mountain ash <u>Sorbus</u> <u>aucuparia</u> L.	B	-	-	-	-	-	-	50	16	14	50	17	12
Cluster bird cherry <u>Padus</u> <u>racemosa</u> (Lam.) Gilib.	C	-	-	-	-	-	-	-	-	-	25	2	-
Sweet mock orange <u>Philadelphus</u> <u>coronarius</u> L.	A	-	-	-	-	-	-	50	9	9	50	12	12

Note: Gas and smoke acted from the southern side of the crown.

The observations indicated that the smoke and gas discharged from industrial concerns have different effects upon the flowering and fruiting of different species of shrubs. The common hawthorne and the red berry elder did not react to the gas and smoke. The Tarter honeysuckle, the European barberry, and the (game) round-leaved serviceberry showed that on the sides of the crowns that were facing the sources of the smoke and gas there were fewer flowers, less fruit setting, and a greater drop in the immature fruit set than was the case on the opposite side, in spite of the fact that this was the southern, more lighted part of the crown. This was especially apparent in the Tartar dogwood where, out of 50 observed flowers (in the upper part of the crown) 18 formed fruit sets and all of these dropped before ripening.

Thus, gas and smoke, discharged by industrial concerns, had little noticeable effect on some individual species of trees and shrubs, while with other species the effect was shown in the decrease of the flowering and in the number of fruit set, as well as in the premature dropping of the young fruit.

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THE EFFECT OF SPECIFIC INDUSTRIAL GASES

ON THE GROWTH OF SOME TREE SPECIES

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From Belorusskoe otdelenie Vsesoyuznogo botanicheskogo obshchestva. Botanika. Issledovaniya. Vyp. V. (Minsk, 1963), p. 150-154.

The injurious effect of some chemical substances on plant growth is known in the literature. Salts of heavy metals (copper, lead, silver, etc.) and such organic substances as ether, chloroform, toluene, ethylene, etc., arrest plant growth. The concentration of injurious gases exerts a decisive influence on the growth increment of plants. Thus, the majority of even the most poisonous substances taken in small concentrations may exert a stimulating rather than a depressing effect on growth (N. A. Maksimov, 1948).

We have made a study of the effect of gases from a chemical plant on the annual increment of shoots. The concentration of the exhaust gases was constant and known. In the area where the trees grew, the concentrations were: methane, 0.0184; ethylene, 0.00262; acetone, 0.00175; and acetic acid, 0.0011 g./m.^{3}.

In selecting experimental plants their origin, age, and location were taken into consideration. The plants selected were the healthiest ones, 10-20 years old, except the elm, which was older. In measuring the growth increment, the close and regular interdependence of the biological characteristics of the various orders of branching were taken into account (E. I. Guseva, 1951). The average total was taken from 10 measurements made on like stories and branching order.

Measurements made on control plants growing in the absence of gases showed that in all studied species the annual growth increment decreased as the branching order increased. This consistent pattern of behavior did not apply to the elm, which can be attributed to it's greater age and to the fact that in old trees the regularlity of growth increment changes appreciably.

The regularity of the annual growth increment was disturbed also in trees and shrubs growing on the site of the industrial enterprise. Particularly great deviations occurred in the southern parts of the crowns, facing the source of exhaust gases (Fig. 1). Shoots of the branching order I lost more of the annual increment on that side of the crown than the others. In many cases, the increments in the orders II and III were higher than in order I. No such cases were observed in the control plants. This indicates that industrial exhausts in the indicated concentrations hampered the annual growth of those shoots in which the growth processes are most intense.

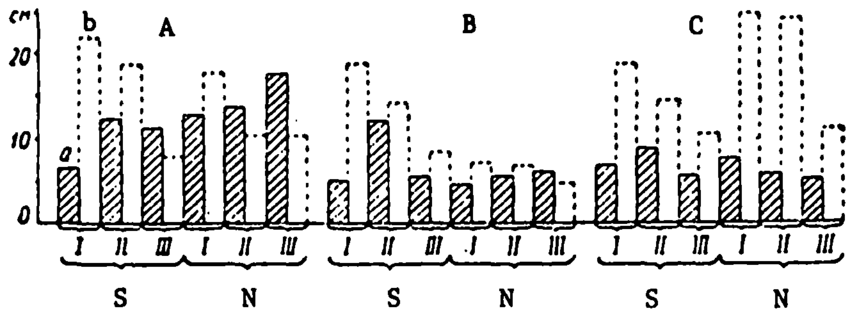

Fig. 1 Growth increment of shoots

A - Crataegus oxyacantha L. (English Hawthorn); B - Cornus alba L. (Tartarian dogwood); C - Quercus robur L. (English oak); S - Southern side of tree crown; N - Northern side; a - Growth increment on the industrial site; b - Control. Roman numerals indicate branching order.

As early as 1911 V. V. Sabashnikov wrote about the effect of industrial gases on the annual growth rings: "It was noticed that the annual rings of trees exposed to a constant action of factory exhausts become narrow and irregular to such a degree that a cross section through the tree makes possible the determination of the approximate year when the adverse effect of the factory started."

The effect of industrial gases on the thickness of annual growth of trees were studied at a chemical plant which produced nitrates. A comparison of cross sections from the trunks of poplars and birches grown on the site of this enterprise and in a location not exposed to gases shows that the annual rings of trees grown on the site of the enterprise produced periodic formations of concentric thickening and thinning zones, which were unrelated to climatic changes and were the result of the variable composition and quantity of the deleterious exhaust gases.

On the industrial site 10 dead poplar trees (Populus balsamifera L.), 20 birches (Betula pubescens Ehrh.), and a willow (Salix fragilis L.) were studied. A comparison graph is drawn on the basis of the study (a) of two birches that died on the industrial site and (b) of one control sample. Except for the gases, the growth conditions and the state of the trees were relatively uniform. Also the climatic and soil conditions could not exert a telling influence. Therefore, a sharp decrease in the growth of certain years can be attributed only to the injurious effect of industrial gases.

As can be seen from the graph (Fig. 2), in the control specimens (C) the annual growth, on the north side of the tree, was, during all the years, to some degree not unlike that of the growth on the south side, though somewhat smaller. The growth curve of trees grown on the industrial site have shown a similar relationship. As the production of nitrates increased, the random venting of nitrogen oxides increased, thereby causing wide-spread destruction of vegetation. An analysis of a cross section through the trunk shows that an old tree (A) was more resistant in the first few years.

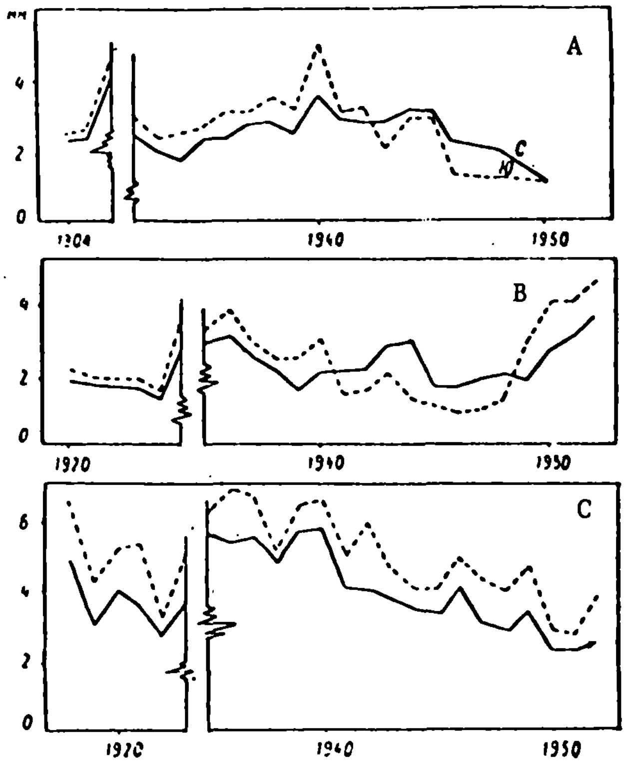

Fig. 2 Annual increment of trunk diameter of European white birch

A and B - On industrial site; C - Control;
N - Northern side of tree trunk;
S - Southern side

Only in the third year, after the volume of injurious exhaust gases increased, did the increment in the thickness of the trunk decline appreciably; but a young tree (B) reacted faster and in the following year its growth declined greatly. In the old tree, in the early years of the gas exposure, the increase in the trunk's diameter on the northern and that on the southern side were equalized (the gases acted on the southern side). Later, however, the growth increase on the northern side exceeded that on the southern side, which is not characteristic of trees growing under normal conditions. In the young tree the growth increment on the northern side of the trunk exceeded that on the southern side in the second year. In the next two years the growth of this young tree increased somewhat. This was apparently because the dying-off of the tree crown on the southern side left the entire undamaged root system to contribute to the growth on the northern side of the trunk. The decline of growth began in the fourth year. The absence of a similar phenomenon in an old tree may be explained by its greater resistance to change in growth pattern.

When the production of nitrates stopped and the venting of nitrogen oxide ceased, the old tree could not recover its previous state and died after two years, whereas the young tree could not recover for two years but later showed a considerable growth. The curves giving the diameter increment of the tree were equalized. In the last few years, in connection with a technological change of the manufacturing process, the composition of the gases changed and their concentration increased. The trees perished en masse. In more resistant species the growth increment declined. Thus, for example, the balsam poplar (Populus balsamifera L.) at the age of 20 had a height of 9 m. and for 16 years the average annual growth increment in its diameter was 8 mm., whereas in the last 4 years it was only 0.6 mm. At present, the tree is completely dead.

Variations in the growth increment of annual rings can serve as index of the injurious effect of various industrial gases on plants. For such an objective, young trees are preferable because they are more responsive to changes of surrounding conditions and recover more rapidly after being affected by gas. The older trees react more slowly, take longer to recover, and as a rule eventually dry up. These differences may be related to the prevalence of different kinds of gas resistance (N. P. Krasinskiy, 1950) at definite ages; in the case of old trees the nature of resistance being anatomical, morphological, and physiological (less oxidation of the cell content), whereas in young trees the biological resistance to gases is greater.

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REACTION OF TREES AND SHRUBBERY TO AIR POLLUTION IN THE FOREST-PARK BELT OF MOSCOW AND MEASURES FOR EXTENDING THE LIFESPAN OF PLANTS

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The present work was undertaken at the suggestion of the Moscow Soviet and at the behest of the Presidium of the U.S.S.R. Academy of Sciences, with the cooperation of the Sanitary and Epidemiological Station of Moscow and the Park Service of the Moscow Soviet. The investigation was carried out in a number of Moscow suburban parks and forests. The main difficulty was to find in areas free of air pollution plantings that would be similar in all their characteristics (i.e., their species composition, age of plants, and soil characteristics, as well as in their hydro-geological conditions and grass stand, etc.) to those of the plots selected for observation in the air-polluted eastern areas of the park-forest belt of Moscow. These plantings were to be used as control or check plots in the study.

Only a carefully worked out method of approach to the study of this biologically complicated problem will enable us to identify the cause of forest destruction. The latter is the result of many factors, such as industrial discharges, changes in the composition or make-up of standing timber caused by untimely and incorrect felling, as well as by compaction of the soil or by changes in the hydrological conditions, etc.

Several areas were chosen for investigation. In the smoke-polluted eastern, northeastern and southeastern areas the sections and trees chosen were as follow: (1) in the suburban Moscow district of the forest-park administration, compartment no. 50 - a 70 to 80-year-old and a 16-year-old pine, compartment no. 53 - a 60 to 70-year-old and a 12 to 14-year-old spruce; (2) in the Mytishchinskiy forest-park administration, compartment no. 19 - a 70 to 80-year-old spruce; (3) in the Kuchinskiy forest-park administration, compartment no. 59 - a 60 to 70-year-old spruce; (4) in the Balashikhinskiy forest-park administration, compartment no. 101 - a 70 to 80-year-old pine. In the non-smoke-polluted western and northwestern areas, the following trees were chosen in the various forest preserves: (1) in the Khlyupinskoe forest preserve - a 70 to 80-year-old pine and a 16-year-old pine; (2) in the Sharapovskoye forest preserve - a 60 to 70-year-old spruce and a 12 to 14-year-old spruce; (3) in the Stepanovskoye forest preserve - a 70 to 80-year-old spruce; (4) in the Nikolina Gora - an 80-year-old pine. The prevailing wind direction in Moscow is from west to east.

The growth of industrial establishments and large enterprises of factories and mills, as well as the development in the last few decades of automotive transport in Moscow, as in many other large cities in the U.S.S.R., caused the discharge into the air of millions of tons of gas, smoke, dust, and other pollutants. Accumulated smoke forming a dense, dirty smog can often be seen over large industrial cities. Quite frequently this dense dirty fog hangs over the city at a height of 500 meters, and the ultraviolet rays have difficulty in penetrating it even in the heat of summer. In most cases, these rays do not reach the earth's surface. In all large industrial cities of the world, because of the man-made smog, insolation decreased during the last 50-60 years by 10-30% as compared with the early part of the century. In this connection it is important to remember that full natural sunshine is the best enemy of bacteria.

The chemical admixtures vented into the air by industrial enterprises and automotive transport also affect negatively the vegetation. A single thermal power station discharges into the air an average of up to 30 tons of noxious gases per day, which is equivalent to 50 tons of sulfuric acid. Oxidation of motor fuel containing tetraethyl lead results in a discharge into the air of world capitals of up to 15 tons of lead daily in the form of minute particles. Each automobile exhausts into the air an average of 6-10 cubic meters of gas. In large cities, millions of cubic meters of noxious substances are discharged into the air (Table 1).

According to the data of many years of records of the Moscow Sanitary and Epidemiological Station (Gabinova, Vasil'eva, Popov, 1961), the maximum concentration of sulfur dioxide in one of the easterly suburbs (Izmaylovskiy Park) occurs in November-February, and the lowest in May-July. In this connection should be noted that the annual average concentration of SO_2 for the period 1955-1960 dropped sharply in this area, apparently because of a general lowering of the SO_2 content in the air of Moscow during this period and of a general improvement in the city air conditions. Similar conditions were found during our investigations of the Moscow forest-park belt (Mytishchinskiy, Podmoskovnyy, Kuchinskiy, and Balashikhinskiy forest-parks). Thus, during May and June neither sulfur dioxide nor nitrogen oxides were found, whereas in October and November they reached a high level at all points, and at some points their concentrations were near lethal (Table 2).

These data justify the conclusion that the most damaging concentrations of gases affect the trees during the autumn-winter season. However, the injury to vegetation by gases is less in winter than in summer, particularly to broad-leaf species because they drop the foliage. It is equally clear that greater gas damage is to be expected to conifers than to broad-leaf species. Meteorological conditions can augment the damaging action of industrial smoke and gases. Fog, dew, precipitation, and a high relative humidity of the air enhance the action of gaseous air admixtures on plants. During autumn and winter air layers at low heights from the land surface contain products of incomplete combustion, which combine with droplets of fog or dew to form condensation nuclei. Separately, the air pollutants (carbon monoxide, carbon dioxide, sulfur dioxide, tars, etc.) are less dangerous and less aggressive than in combination. In a fog, all these substances concentrate and form additively an injurious mixture, more dangerous to animals and plants. Wind direction and intensity can also increase their adverse effect on vegetation.

Table 1

Content of some chemical admixtures in the air of smoke polluted (A) and smoke-free (B) areas of the Moscow forest-park belt.

	Place of sampling	Date	Time of day	SO_2	Nitrogen oxides	Active chlorine	Chlorides Cl ion	Remarks (where air samples were taken)
A.	Podmoskovnyy forest-park, compartment 50, 80-year-old pine	26/V	10-12	0.15-0.36	Not found	0.037--0.058	Not determined	Glade near edge of thinned 80-year-old pine stand
B.	Khlyupinskiy forest preserve, near Zvenigorod, 70 to 80-year-old pine	14/VIII	11-13	0.3-0.42	0.11-0.23	Not found	Not found	Same place
		2/VI	13-15	Not found	Not determined	" "	0.13-0.20	Glade behind forest
A.	Podmoskovnyy forest-park, compartment 53, spruce	26/V	13-15	" "	" "	0.019--0.037	Not determined	Clearing in forest
		14/VII	14-15	0.42	0.11-0.23	Not found	0.12-0.12	Near edge in open space
A.	Balachikhinskiy forest-park, compartment 101, 80 to 90-year-old pine	30/V	16-18	Not found	Not found	" "	0.03-0.05	In forest, 20-30 m. from forest edge, near a railroad track in an open space
		29/VIII	11-12	0.48-0.72	0.117--0.117	" "	0.12-0.12	Open space near forest
		7/IX	11-12	0.15-0.48	Not found	" "	Not found	Open space between single trees at height of 15 m.
B.	Nikolina Gora, sanitarium, thin stand of pines, 75 to 80 years old	9/VI	15-17	Not found	0.12-0.12	" "	0.13-0.23	Open space on shore of r. Moskva, near bridge
		1/IX	12-14	0.42-0.72	0.117--0.936	0.01-0.03	Not determined	Same place

Table 1 (Continued)

	Place of Sampling	Date	Time of day	SO_2	Nitrogen oxides	Active chlorine	Chlorides Cl ion	Remarks (where air samples were taken)
A.	Kuchinskiy forest-park, compartment 59-67, 80-year-old spruce, compartment 85-70, 80-year-old spruce	16/VI	12-14	Not found	Not found	Not found	0.17-0.12	Small glade in forest near "Koroviy prud" cow pond
		17/VI	15-16:35	0.3-0.42	0.117-0.234	0.1-0.1	0.0-0.12	Open space near forest edge
B.	Sharapovskoye forest preserve, compartment 80-85, spruce	2/VI	15-17	Not found	Not found	Not found	0.13-0.20	Inside the forest on a small glade near the forest edge
		9/VI	12-14	" "	" "	" "	0.13-0.37	Felling area
A.	Mytishchinskiy forest-park, compartment 19, 70 to 75-year-old spruce	30/V	11-13	" "	" "	" "	0.13-0.27	Near forest edge, at an intersectional clearing, inside forest
	Same place, compartment 10, 70 to 75-year-old spruce	17/VIII	11-12	0.3-0.42	0.117-0.234	0.01-0.01	0.03	Open space near dense forest
	Same place, compartment 12, adjacent to 19, spruce	5/IX	11-13	Not found	Not found	Not found	0.12-0.12	Intersectional clearing. In the crown of trees, at a height of 15 m. Edge of compartment
	Same place, compartment 10, spruce	24/X		0.45-0.81	0.31-0.62	" "	0.13-0.13	Open space near dense forest stand

Table 2

Content of some pollutants in the air of the Moscow forest-park belt (mg./m.^{3})

Place of sampling	SO_2		Nitrogen oxides	
	May-June	Aug.-Oct.	May-June	Aug.-Oct.
Podmoskovnyy forest-park				
section 50	0.15-0.30	0.38-0.42	Not found	0.170-0.23
section 53	Not found	0.42	" "	0.150-0.23
Kuchinskiy forest-park	" "	0.37-0.42	" "	0.205
Balachikhinskiy forest-park	" "	0.48-0.72	" "	0.117
Mytishchinkskiy forest-park	" "	0.48-0.81	" "	0.31 -0.62

In viewing the effect of air pollutants on vegetation, two aspects can be brought out:

1. The protective role of green plantings as a shield blocking the penetration of noxious air downwind into the depth of the stand. Dealing with this problem are the interesting works of V. F. Dokuchaeva (1959) and others, which recommend the planting of shelter belts for the protection of more valuable species against smoke and noxious gases.

2. The negative physiological effect of mechanical and chemical air pollutants on vegetation. This effect manifests itself in two ways.

a. The direct effect of gases on the assimilation apparatus of the leaves: as a result of absorption of SO_2 through the stomata assimilation is disturbed, photosynthesis lowered, chloroplast iron inactivated, respiration frequently increased (the respiration coefficient exceeds 1), vitamin B destroyed, an unfavorable protein and carbohydrate balance sets in, and the accumulation of silicic acid and strontium in the leaves increases.

This is followed by the appearance of external symptoms of disturbed metabolism, injury to leaf tissue, leaf necrosis, all of which affect the growth of the leaf and the increment of the tree's height and diameter. Our observations in this respect coincide with those of foreign authors. We have shown that under the influence of smoke and gases the conifer needles grow more intensively in length than in thickness, whereas the reverse is observed in the leaves of broad-leaf species. In the initial growth stage of a leaf, gases stimulate the growth in width while in subsequent stages they arrest growth, thus preventing the leaves from attaining normal shape. This leads to an increase in the xeromorphy of the leaf's structure. In addition, we observed in a young, 16-year-old pine, in the Podmovokovnyy forest-park (compartment 50) that the tips of the needles turned as a rule bright yellow, below which the needles were of a faded, drab dark green color and foreshortened. At the same time, in a similar stand of pines (Khlyupinskoe preserve) where the air is free of pollutants, the needles showed no sign of disease and the annual increment in height and diameter was appreciably greater than of the pines in the Podmoskovnoe forest-park.

Data in Table 3 lead to the conclusion that the needles and the growth buds of spruce and pines growing in the smoke-polluted areas of the Moscow forest-park belt are greatly affected by air pollution. In all cases, including young and old trees, the absolute green and dry weight and length of the needles drop, the average linear length increment of apex shoots declines, the average weight of apex and lateral buds diminishes, all of which is connected with a weakening of the synthesizing activity of the leaves and of the growth processes. An inverse relationship was observed in 1961 in the number of needles per unit length of shoot, that is, the number of needles per cm. on trees growing in smoke-polluted areas was appreciably greater than on trees growing in pure air. The needles on the apex and lateral shoots were broomlike, tightly bunched and appreciably shorter.

More convincing proof was obtained in spruce stands (80 to 85-year-old) growing in smoke-polluted and unpolluted areas of the Moscow forest-park belt. One example is quoted in Table 4.

Table 3

Biometric data of pine and spruce needles of 1961 growth in smoke polluted (A) and smoke-free (B) areas of the Moscow forest-park belt.

Place of sampling (sample trees)	Raw weight of 1000 needles		Air-dried wt. of 1000 needles		Moisture in needles %	Average length of needle		Number of needles per 1 cm.		Average increment of apex shoot for 1961		Average wt. of apex bud		Average wt. of bud of a lateral 1961 shoot	
	g.	% of contr.	g.	% of contr.		cm.	% of contr.		% of contr.	cm.	% of contr.	mg.	% of contr.	mg.	% of contr.
I															
A. Mytischinskiy forest-park, 70 to 75-year-old spruce, compartment 19	5.35	48.9	3.84	71.3	28.2(+?)	1.1	78.6	28.8	119.0	5.8	89.2	99.4	87.0	28.7	90.0
B. Stepanovskiy forest preserve, 70-year-old spruce	10.94	100	5.39	100	52.0	1.4	100	24.2	100	6.5	100	114.4	100	32.0	100
II															
A. Kuchinskiy forest-park, 80-year-old spruce, compartment 59-57	8.83	86.7	4.41	93.8	50.0	1.15	87.1	29.3	113.5	4.0	42.1	80.0	59.1	27.5	86.8
B. Sharapovskoe forest preserve, 80 to 85-year-old	10.18	100	4.70	100	55.0	1.32	100	25.8	100	9.5	100	135.4	100	31.7	100
III															
A. Podmoskovskiy forest-park, 80 to 90-year-old pine, compartment 50	15.94	48.7	7.88	46.7	50.3	3.42	62.8	35.0	137.2	1.8	66.7	10.5	19.1	-	-
B. Khlyupinskoye forest preserve, 80-year-old pine	32.75	100	16.90	100	47.0(?)	5.45	100	25.5	100	2.7	100	65.0	100	-	-

Table 3 (Continued)

Place of sampling (sample trees)	Raw weight of 1000 needles		Air-dried wt. of 1000 needles		Moisture in needles %	Average length of needle		Number of needles per 1 cm.		Average increment of apex shoot for 1961		Average wt. of apex bud		Average wt. of bud of a lateral 1961 shoot	
	g.	% of contr.	g.	% of contr.		cm.	% of contr.		% of contr.	cm.	% of contr	mg.	% of contr.	mg.	% of contr.
IV															
A. Balashikhinskiy forest-park, 80 to 90-year-old pine	19.35	66.0	9.58	65.2	53.2	3.8	61.8	28.2	91.0	3.2	53.3	28.0	38.9	3.0	12.3
B. Nikolina Gora, 75 to 80-year-old pine	32.39	100	14.68	100	55.0	6.15	100	31.0	100	6.0	100	72.0	100	24.5	100
V															
A. Podmoskovskiy forest-park, 12-year-old pine, compartment 50	57.55	95.5	26.52	94.2	53.0	6.6	100	12.8	139.0	34.6	79.7	237.2	61.5	86.6	61.8
B. Khlyupinskiy forest preserve, 12 to 14-year-old pine	60.28	100	28.13	100	54.6	6.5	100	9.2	100	43.4	100	38.58	100	140.2	100

Table 4

Comparative growth increments of spruce plantings in smoke-polluted and smoke-free areas of the Moscow region

	Number of trees, %			Annual increment in height, cm.				
	withered	half withered	healthy	1961	1960	1959	1958	1957
Smoke-polluted plot Spruce stand, 80 years old, Kuchinskiy forest-park, 194 trees	8.1	76.5	15.5	12.0-43%	7.0-72%	8.5-73%	8.0-56.7	10.2-51.4
Smoke-free plot Spruce stand, 85 years old, Shorokhovo, Zvenigorod district, 210 trees (control of Kuchin plantings)	0.54	1.0	98.5	21.0	25.0	31.0	18.5	21.0

It follows from the quoted data that noxious gas pollutants reduce the number of healthy trees 6-fold and the number of withered and dried-up trees rose more than 85-times as compared with stands in pure air. The annual height increment for the last 5 years declined 43-73%. According to data of senior forest pathologist in the Moscow forest-park administration, Yu. A. Troyanovskaya, the large number of weakened and drying-up trees in Kuchino greatly contributed to the development of numerous and powerful sources of severe infestation of insect pests. These include forest pests which attack the trunk of the tree (such as various bark beetles and destructive woodborers of the Scolytidae [Ipidae] spp., as well as the Norway spruce weevil, Norway spruce black long-hornet beetles, etc.) At the same time, in a control or check area of 0.5 hectare of a spruce stand, these pests were encountered only on 1-2 trees.

b. The indirect action of noxious gases in the air appears also through the soil. Although the soil exerts to some extent a buffering action, systematic and prolonged acidification changes the course of chemical processes. The soil grows poorer in bases, its gas equilibrium is upset, its microbiological activity is disturbed, and it accumulates soluble salts of aluminum and strontium. This upsets the normal plant nutritive regime (or status) of the soil. Ultimately, all the particles of smoke, soot, dust, and gases polluting the air end up in the soil. Some of these, such as silicon, fluorine, lead, copper, zinc, chromium, strontium, and others, in small doses, are necessary microelements but in large amounts they are toxic. Heavy metals penetrate the soil to a depth of 25 centimeters. The soil absorbs a large quantity of these substances, as well as smoke, soot, and dust. A good example can be seen near Moscow, in the Podolssk region at the edge of the town of Pavshino, where cement mills are located; the soil and the vegetation around them are covered with a thick layer of gray dust. True, the floating dust is not as detrimental to soil and plants as are the smoke and gases but in combination with them its action is very aggressive.

It should be noted that the deleterious effect of chemical and mechanical air pollutants is more pronounced on forest than on tilled soils, regardless of the higher buffer capacity of the former and their higher humus content. The tilled soils are plowed and fertilized every year. It is known that the addition of mineral fertilizer (calcium and magnesium) and the tilling are factors in overcoming the ill effects of smoke and gas. Smoke pollution causes continuous acidification of forest soils. The acid components of smoke and gases are not buffered by forest soils and cause more structure degradation and lower fertility than in tilled soils.

Various kinds of trees and shrubs exhibit different degrees of biological resistance to noxious chemical and mechanical impurities that pollute the air. The most resistant of the conifers is larch because it changes its needles every year. Next is pine, which changes its needles every 2 or 3 years; next to the pine is fir, which changes its needles every 3-5 years; and finally comes spruce, which changes its needles once in 7 years. Some authorities consider the fir as the most susceptible to noxious air pollutants.

Some investigators consider four groups of trees in relation to their gas resistance: highly resistant, slightly susceptible, susceptible, and very susceptible. These investigators have used the following criteria: premature fall of leaves or of needles, appearance of spots on leaves, bareness of tree tops, lowered resistance to pests, and arrested increment of height and of diameter (Paprzycki, 1960). We have used the same criteria in estimating the degree of injury caused by smoke and gas to the growth of spruce and pine stands in the eastern sections of the Moscow forest-park belt.

Many investigators contend that the resistance of trees to smoke gases changes with the local conditions and with the age of trees. Young spruce appear to be more resistant to gases. Clear signs of gas damage were found only in the barling stage. Low quality, thin stands were usually found on poor soils but this differed with the age of trees. In a 90-year-old spruce and pine stand, IV and II bonitats, the spruce died out completely, while the pine was well preserved. In another place, in a 60-year-old pine stand, the Scotch pine was less resistant to SO_2, HF, and arsenical compounds than the Weymouth pine. Under the influence of sulfur oxides, the pine produces bunched shoots on its top and forms a multi-apex crown. These signs appear to a lesser extent in the Weymouth pine. The gas-resistant pine varieties have a darker needle color and a larger angle at which the needles are fastened to the shoots, as compared with the less resistant varieties having a paler needle color, short needles, and a small angle of needle attachment (Pelz, 1958). It can be considered as proven that a high resistance to SO_2 and SO_3 have been found in the following species: Persian walnut, spruce, pine, ash, beech, woadwaxen, oats, alfalfa, lentil, heliotrope, primrose, sweetpea, and nasturtium; high resistance to Cl and HCl is characteristic of Persian walnut, cherry, and grapevine; and high resistance to F and HF has been found in the grapevine, apricot, and gladiolus. Particularly sensitive to smoke gases are some fungi (Oidium and Microsphaer guezina). Least sensitive to smoke gases are: oak, hornbeam, linden, maple, elm, birch, alder, willow, poplar, mulberry, hawthorn, and elder (Antipov, 1957).

It was shown that when the leaves of apricots contain 3-10 mg. of fluorine per 100 g. of their dry weight, the tree shows definite signs of injury, whereas when they contain chlorine 200-300 g. dry leaves no injury was noticeable (Translator's note: There is an obvious misprint in the preceding phrase which renders the text unclear). Fluorine not exceeding 0.1 mg. and chlorine not over 5-10 mg. per 100 g. of dry weight of leaves are considered tolerable for the normal growth of trees.

Lately, considerable work has been done in the technique of estimating noxious admixtures in the air. It can be based either on the external symptoms of plants or on analysis of leaves (high contents of SO_2 and wax). In other cases bio-indicators have been used with considerable success, namely: gladiolus for the detection of fluorine; pine (Pinus taeda) capable of accumulating sulfates, without showing signs of damage; bluegrass -- sensitive to general air pollution; and sunflower as well as mazzard cherry -- sensitive to sulfur oxides.

In conclusion, it is necessary to point out possible means for increasing the resistance of tree stands under conditions of smoke gas pollution and particularly, in the eastern part of the Moscow forest-park belt. The advisability of using chemical fertilizers for this purpose is emphasized in literature. Our own experience of many years in studying the physiology of soil plant nutrition confirms this view. Systematic application of mineral fertilizer to stands subject to pollution by acid gases and smoke can, without doubt, greatly improve the chemical and physical conditions of the forest soils, as well as their microflora and the nutrition of grasses and woody plants. Here, of utmost importance are lime and lime-magnesia (limestone, dolomite, marl, etc.) augmented by nitrates and phosphates. It is advisable to apply in autumn, every 3-5 years, 2-3 tn./ha. of lime (CaO), dolomite or marl; this is a suitable, effective, and economical procedure in the agro-technology of forest-park management. In the following spring should be added 100 kg./ha. of ammonium nitrate; this is best broadcast and then worked in with rakes, hoes, or mattocks. Young trees can also be sprayed with a 0.5% urea solution, which will greatly improve their growth.

At any rate, adopting a system of fertilizing the forest-park belts of the cities is a powerful means for improving the structure and fertility of the soil as well as for improving the life activity and productivity of tree stands and their increasing resistance to pests and to the ravages of city smoke gases.

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CURRENT CONDITIONS AND SCIENTIFIC PROBLEMS IN STUDYING THE INJURIOUS EFFECTS OF INDUSTRIAL POLLUTANTS ON PLANTS AND IN DEVELOPING METHODS FOR CONTROLLING THEM IN THE URALS

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As the tempo of industrialization in the Urals accelerates, industry exerts a constantly increasing diverse and profound effect on the natural resources of the region, including that of vegetation. This occurs through various factors, in various ways, of which the most significant is that of industrial pollution. Numerous ash piles from power stations, plants and factories, and large tracts covered by wastes from mining, occupy considerable areas in the Urals. On them and near them there is usually no vegetative cover, or else the vegetation found there comprises useless grasses, trees, and shrubs. Many industrial enterprises dump their waste water into rivers and lakes, thereby destroying aquatic and littoral vegetation. Finally, the smokestacks of an enormous number of industrial developments belch ash, soot, sulfur dioxide, and other gases which strongly pollute the air and soil around them and create unfavorable conditions for plant growth on large areas extending over hundreds of square kilometers. The magnitude of this process is exemplified by the city of Sverdlovsk where the boilers (of power stations) alone discharge into the air 400 tons of ash and over 100 tons of sulfur dioxide per day. In addition, various enterprises, automotive traffic, and railroads contribute their share to air pollution.

At the present, there are no accurate figures concerning the negative effect of industrial pollutants on vegetation. However, for the larger Ural Region including Perm, Sverdlovsk, Chelyabinsk, and Orenburg districts, Bashkir and Udmurt A.S.S.R. our preliminary estimates of damaged areas are that these extend over 500,000 hectares.

It should be kept in mind that similar conditions obtain primarily and in a particularly acute form in population centers, i.e., in areas where vegetation is especially valuable to man.

All this means that the time is ripe to address ourselves seriously to the task of eliminating the deleterious consequences of air and soil pollution destructive of vegetation. However, in the Ural Region as well as in many other areas of the country, the problem was not investigated scientifically until recently, and if some attempts in this direction were made, they were one-sided and dealt with specific issues rather than with the overall problem. It can be assumed that the scientific and theoretical bases of the problem were not worked out, its main points are not clearly differentiated, and guidelines for such investigation were not formulated.

In defining the basic tasks of the problem of the interrelation of vegetation and industrial pollution it is advisable to start with the source of pollution affecting the environment and life of the plant.

Under the influence of industrial pollution, a whole series of factors affecting plant life change simultaneously, even though the changes may be of different magnitude. In examining the most important of these, we shall attempt to describe briefly the extent to which these problems were investigated in the Ural Region and to suggest means for combatting their adverse effect on plant life.

It should be pointed out at the very beginning that in so short a communication it is not possible to touch upon the effect of radioactive pollution on plant life. This is a rather special problem at the present and requires a separate treatment.

Changes in the Gaseous Composition of Atmospheric Air

The air of industrial areas has an increased concentration of extraneous gases. The composition of these gases varies and depends on the type and nature of local industry. In almost all cases, the content of sulfur dioxide increases to 0.5-1.5 mg./m.^{3}, or more, within a radius of 1-2 km. from the source (according to V. A. Ryazanov the permissible concentration is 0.37 mg./m.^{3}) and the carbon monoxide content increases to 20-35 mg./m.^{3}. (near metallurgical plants). Near aluminum and, frequently, near copper smelters, the fluorine content of the air increases to 0.4 mg./m.^{3} in a radius of 10 km.

The concentration of carbon dioxide (CO_2) also increases. In the air appear vapors of sulfuric acid, hydrogen chloride, ammonia, nitrogen oxides, and the like. Most of these substances penetrate through the stomata into the intercellular spaces, and precipitate as liquid acids on the surfaces of leaves and stems, causing burns of various degrees of severity. In the former case, the essence of the injurious effect of acid gases, according to N. P. Krasinskiy, consists of photodynamic chlorophyll action. But this does not exhaust the damage, as was pointed out by Krasinskiy himself (1950). In the latter case, the burns are the result of a mechanical digestion of leaf tissue by the strong acids. The different types of injuries must be considered separately, regrettably, however, this is not always done by those who investigate gas resistance of plants.

Plant physiologists are faced by a serious task, namely, to study the causes of gas resistance of plant organisms without restricting themselves to the oxidation theory of the cell content. In the last few years, the botanical gardens of the Institute of Biology of the Ural Branch of the U.S.S.R. Academy of Sciences began some work in this field. V. S. Nikolaevskiy confirmed the assumption of N. P. Krasinskiy that the quantity of oxidizable substances in the leaves of a number of woody plants may be accepted as an index of resistance to acid gases. Resistant species, e.g., box elder, contain less oxidizable matter than species severely injured, such as dwarf apple and European white birch. Also, changes are noticeable in the course of the growing period. The quantity of oxidizable substances increases 1.5-2 times toward autumn; this is in agreement with an increased leaf vulnerability to gases toward the end of summer. The established correlation of gas resistance with the intensity of life processes is also significant: the more resistant plants usually show a lower intensity of photosynthesis and respiration. There are also some preliminary data relative to the great importance of the anatomy and morphology of the leaves to the gas resistance of woody plants.

Other investigations on the gas resistance of plants (predominantly woody) were also carried out in the Ural Region. Among these should be mentioned the work of the Ural Institute of the U.S.S.R. Academy of Municipal Economy, the work of some verdant-plant specialists in such cities as Krasnoural'sk (M. V. Bulgakov), Berezniki, as well as in the Chelyabinsk district. However, the purpose of these investigations was not the physiological or anatomical causes of gas resistance. Generally, they gave an overall evaluation of the resistance of plants to air and soil pollution. Recently, Yu. Z. Kulagin studied the physiology of plants growing under conditions of increased gas pollution.

High Dust Content of the Air

In the southern reaches of the Urals, naturally occurring wind erosion brings about a high dust content of the air.

In the central Urals and in the forest belt of the southern regions dust pollution of the air is caused essentially by power stations and coal-fired central generating plants. Usually, the dust carries small particles of coal, ash, and frequently, depending on the nature of the industry, particles of silica, aluminum oxides, caustic magnesite, and compounds of sulfur, lead, fluorine, copper, arsenic, and zinc. Dust pollution in some areas of the Urals was studied in detail by the Institute of Industrial Hygiene and Occupational Diseases (Sverdlovsk).

Dust of a particle size 0.1-100 microns settles at a distance of several scores of meters to several kilometers from its source. The quantity of settled dust is quite considerable and may reach several hundred grams per square meter per year. The suspended dust consists of particles 0.001-10 microns and its content in the air is 0.4-0.6 $mg./m.^3$ (Thomson, 1959).

Dust settled on leaves interferes with the normal life processes by sealing the stomata, causing the leaves to overheat, and shading off the light. This, in turn, decreases the intensity of photosynthesis and causes a 16-27% decline in the accrual of vegetative mass (Ershov, 1959). Poisonous oxides of lead, fluorine, copper, and the like in the dust causes poisoning and death of leaves.

In the Ural region valuable studies on the effect of dust pollution on woody plants have been carried out for a number of years by the Institute of Biology of the Ural Branch of the U.S.S.R. Academy of Sciences and the Bashkir State University.

Most of the investigators concentrate on the interaction of the leaf and the dust particles, skirting the phenomena of stimulation and of depression of shoot growth. The same is true of the study of the effect of gases on growth. Yet, a growing young shoot interacts actively with various chemical agents. This is attested in the numerous works dealing with the action of gibberellin. Thus, our experiments with woody plants showed that a bud of a leafy species is more sensitive to a gibberellin solution placed on the bud's integument than are needle plants.

It should be taken into account that among the dust particles and gases in the air surrounding cities and towns are many physiologically active substances and irritants.

It should also be noted that city air contains more carbon dioxide, which is beneficial for the photosynthesis of plants.

The problems of combatting dust and gas pollution of air remain for the present unsolved, not only in the Ural Region but in our country as a whole as well as in most foreign lands. Sparging of tree tops and of lawns and flowers is practiced in many cities. This is quite effective when dealing with a non-cementing dust and in small areas. However, when the dust forms a dense film on the leaves and shoots it becomes necessary to use various solvents, the composition of which depends on the substances in the dust.

The improvement of the soil, which in turn improves the vitality of the plant, is also of great importance. Plant selection is another means of protection against the noxious effect of gases and dust. Forms and varieties should be selected which, because of anatomical structure of the leaf and shoot integument, retard the penetration of noxious substances into the parenchyma. Also, plants capable of recovery after injury should be chosen.

Change in the Physical and Chemical Properties of Soil

Here seven basic trends are to be distinguished: a) the formation of dumps of various kinds; b) the addition to the soil of various particles, settling out from smoke and as result of wind-blown dust from the dumps; c) the effect of industrial waste water; d) the soil pollution in the parking areas of auto-transport; e) the fills and dug ground resulting from construction excavations; f) the pollution by garbage in settled areas; g) the compaction of soil in areas frequented by people (parks and suburban forests). The last two trends are not directly related to industrial pollution. However, it is hard to separate results caused by industrial pollution from those caused by household waste or by compaction by people because all these negative phenomena appear simultaneously. On some of these problems there exists a voluminous literature. For the Ural Region there exist the works of the Ural State University (V. V. Tarchevskiy) on dumps and those of the Institute of Municipal Economy (E. T. Mamaeva) on excavated soil, as well as other works.

Of the most urgent problems in making the cities verdant the most vital is that of finding the means to reclaim ash piles and dumps of mine overburden. These wastes affect adversely not only vegetation but, primarily, the inhabited areas in many cities and towns in the Urals. Therefore, the studies concerning classification of waste piles and dumps, soil formations under these conditions, and the biology of plant groups growing under conditions of an excess of some minerals in the soil and of insufficient moisture and nitrogenous nutrients are of special significance.

The changes occurring in soils under the influence of excessive dust precipitated from smoke is not studied sufficiently. Although reliable data are scarce, it can be assumed that the upper soil horizons are enriched with microelements and that soil acidity and microflora have changed.

The questions of soil formation in cities in conditions of extensive pollution and soil compaction are of special significance. Here frequently come into play rules entirely different from those governing natural soils. It must be noted that, for the present, soil scientists are as yet not too much concerned with the problems of soil formation in areas of intensive human activity, although this problem is becoming increasingly urgent and decisive in the process of soil condition changes.

There is very little material dealing with the suitability of different soil groups of various degrees of contamination: a) for growing lawns and ornamental plant species utilized in landscaping and in making cities verdant; and b) for various trees and shrubs grown in forested areas. Information concerning the effect of salt accumulation in soils or the effect of various quantities of slag, rubbish, or wastes on plants is either totally lacking or quite contradictory.

The effect of industrial pollution on the vegetation of suburban parks, gardens, and greenswards is combined with the action of profound physical changes resulting from compaction and from disturbance of natural runoff. It is frequently overlooked that injury to the soil by noxious gases and dust from various industries occurs simultaneously with impeded aeration of the soil and with disturbance of its structure. It is our opinion that studies should stress the need to clarify the complete role of the various factors conducive to the change of plant environment.

The effect of industrial waste water was sufficiently well studied in relation to its action on fish life of a body of water. As is known, the fish assets of the rivers and lakes of the Urals are greatly diminished, particularly in the last decades and even during the last few years, as results of dumping industrial waste waters. However, little work has been done in ascertaining the effect of industrial waste in so far as it brings about changes in plant life of the watersheds and shore areas, and the resistance of various plant species under the new environmental conditions.

Changes in the Biological Environment of the Plant Habitat

The increased air and soil pollution by industrial wastes greatly affects the living organisms interacting with plants (particularly affected are the symbiotic organisms living in areas of maximum pollution). This, in turn, disturbs the natural biological links and disrupts biocoenosis. Depending on the group of bio-organisms, the basic changes occurring in areas of industrial pollution can be thus schematized as taking place: a) in the species composition of soil flora and fauna; b) in the species composition of pathogenic microorganisms; c) in the species composition of insects, whether injurious to plants, carrying pollen, or carrying disease, also d) in the composition of birds and mammals feeding on plants, on insects and other arthropods, or on worms coming in contact with plants.

The importance of these organisms in plant life is well known, although many facets of their interrelationship are as yet obscure. This emphasizes the significance of the dislocations in the biocoenosis caused by the extinction or suppression of some microorganisms and other life forms. There are at the present a number of investigations that enable one to draw conclusions as to some details relative to changes in the composition of soil bacteria and fungi as well as of lichens as a result of gas and dust pollution of the air. A great amount of work has been done by the medical and sanitary service in studying water and air pollution in cities. However, these investigations did not deal with problems related to the changes in the biotic environment of plants.

Thus, this important field of research is wide-open. Of paramount importance is the study of the effect of industrial pollutants on the composition, ecology, and mode of life of numerous pests and parasites among the microorganisms and insects.

There are some data for example, which suggest that seed of many species of trees and shrubs grown in intensely air-polluted surroundings are less subject to diseases. It should be pointed out that their germination and growth vigor were higher (investigations of V. G. Antipov, Leningrad, 1957). Preliminary studies also show that some pest insects are less often encountered in cities.

At the same time it should be remembered that plants weakened by adverse city conditions may be more subject to various diseases and pest attacks. Thus, in the verdant plantings of Sverdlovsk as well as of other cities there is a widespread occurrence of the following: bacterial canker of balsam poplar; powdery mildew of gooseberries; fungal and bacterial diseases of gladioli, dahlias, and phlox. Such pests as aphids, leaf moths, sawflies, fruit moths, and the like are also of wide occurrence there. When studying the ecology of living organisms in polluted areas, the enormous effect of various chemicals used in forestry, landscaping and fruit growing for combatting pests and weeds should not be overlooked.

Many of our higher plants and, above all, the widely distributed conifers, such as pine, fir, and larch, have on their roots mycorrhiza. Numerous studies have shown that destruction of mycorrhiza fungus weakens the host plant and may cause its withering. The mycorrhiza fungus is very sensitive to soil conditions and it is affected by soil pollution. We are thus faced with the necessity of investigating the complex effects of unfavorable plant growth conditions encountered near cities, towns, and industrial enterprises. It is quite possible that many cases of injury to plantings, particularly, to conifers, are directly attributable to the destruction of mycorrhiza fungus. This is pointed out in great detail by Yu. Z. Kulagin (1961) in his work on the greenbelt of the city of Satki. In working out measures to prevent the withering of conifers, the proper conclusions must be drawn from the above in order to ameliorate the soil environment for the plants by means of the establishment of favorable conditions for the survival of mycorrhiza.

Care of the soil is basic in combatting the ill effects of industrial pollution. The water-air properties of the soil should be improved, its fertility increased, favorable conditions for soil microorganisms created, soil reaction adjusted as needed, and the harmful effect of pollutants neutralized by addition of suitable chemicals and adsorbents.

Improving plant nutrition will lead to the general recovery of the plants and will increase the resistance of their above-ground parts to gas and dust.

Regrettably, these methods for preventing or neutralizing the adverse effects of pollution have not been studied sufficiently as yet in the Urals. The green plantings in the cities are fertilized but not much else is practiced as yet in the maintainence and care of their soil environment.

Lately, the Institute of Municipal Economy and the Botanical Garden of the city of Sverdlovsk started a study of the effect of fertilizer on plant habitats in areas grossly polluted by industrial waste. Preliminary data obtained from the plots established by the Botanical Garden in the city of Revda indicate that fertilization improves greatly soil conditions and enables plant life in areas where otherwise none could be sustained.

It is sometimes said that combatting pollution is a temporary task inasmuch as its severity declines. Indeed, as technical means of control of noxious gases and dust at their source improve, as the very technological processes of industries improve, and as transport as well as industry are to change to other fuels, the air and soil pollution will diminish. However, it will never cease entirely because part of the waste will always be carried out beyond the confines of industrial units. Also, new industries will arise for which effective waste control will not yet be available. The increase in population also contributes to various forms of pollution. Undoubtedly, there must be a constant increase of the areas taken up by mine wastes, excavations, fills, and disturbed soil resulting from the accelerated tempo of building activity, as well as from increased volume and scale of mining operations and of factory building.

Consequently, the importance of counteracting pollution will not diminish. It is, therefore, imperative to augment the scientific research work in this area in order to discover and to ascertain the regularity and natural development of plant resistance on the basis of which there could be developed methods of combatting the injurious effects of noxious gases, dust, and soil pollution.

In our opinion, these then are the concrete problems facing the scientific institutions:

1. Formulation of a general theory of gas and dust resistance of plants. To this end it is necessary to carry out systematic studies of the physiology, anatomy, and morphology of at least three groups of plants: angiospermous herbaceous; angiospermous deciduous; and gymnospermous evergreen woody plants. The latter must be paid special attention. On the basis of these studies, methods should be worked out for combatting the ill effects of air pollution and for protecting plants from gas injury.

2. Investigation of soil formation and plant cover of dumps, ash piles, excavation waste, disturbed ground, and fills. This should comprise soil, geobotanical, and microbiological studies, combined with testing of various species, varieties, and forms of plants under these conditions.

3. Investigation of plant nutrition under conditions of increased salt content, and of changed water and air conditions, and in the presence of extraneous and frequently poisonous admixtures. The results of these investigations combined with the ones mentioned in the preceding Item 2 will make it possible to formulate effective recommendations for reclamation of disturbed territories, by biological means.

4. Elaboration of plant and plant group classification under conditions of heavy air and soil pollution. The first preliminary stage of such classification is available now in the data of numerous studies conducted by various investigators. A more exact, and scientifically well-grounded, classification will be developed upon completion of more thorough and detailed studies.

5. Methods of evaluating air and soil pollution in relation to the suitability of the polluted environment for growing various species of plants. For the present, in most cases there is a lack of reliable indicators and data concerning the gas composition in the air or of the degree of salinity and pollution of soil, on the basis of which recommendations could be made relative to the selection and production of suitable plants. It is unknown at which concentrations of the various gases, salts, and the like, begin the unfavorable effects on plant growth in relation to the environmental conditions and age of plants. The development of leaf diagnosis, widely used in agriculture for determining plant needs (Magnitskiy, 1958; Childers, 1960, and others), may be useful in this connection.

6. Investigation of the effect of industrial pollution on microorganisms and fauna in verdant plantings of suburban belts as related to possible changes in the biocoenosis.

The foregoing enumerated problems constitute some of the major basic tasks facing investigators. Their solution requires much effort. Of great significance is the problem of coordinating the scientific work dealing with the investigations of the effect of industrial pollution on plants. Such coordination should be applied within the framework of an entire geographical and economical region, such as the one constituted by the Ural Region. This coordinating task should be vested, in our opinion, in the commissions for the preservation or conservation of nature at the various branches of the U.S.S.R. Academy of Sciences. In this particular case, we have in mind the Ural Branch, which has already started such studies. The individual commissions for nature preservation of the various branches of the Academy should be united into a suitable body embracing the entire country. Such a complex scientific problem cannot be undertaken without properly organized coordination. In tackling the problem of pollution effects a special role, in our opinion, should be undertaken by the botanical gardens.

Botanical gardens are singularly equipped to undertake such investigations by virtue of a number of reasons. In the first place our botanical gardens are located in large industrial centers where generally one finds that the ecological environment is severely disturbed. There is, therefore, the opportunity to study the types of pollution directly on the territory of the botanical gardens, and also extensive experimentation can be carried out there. Secondly, only the botanical gardens provide conditions conducive to long-term observations of plants, soils, and fauna, while excluding extraneous factors and their effects which frequently disturb and indeed impede such work in other places. And, thirdly, botanical gardens usually have a staff of scientifically trained personnel capable of experimental work, and have the necessary equipment and apparatus. In addition, scientists from other institutions lacking experimental facilities can join in the work of the botanical gardens. The ties between the botanical gardens, institutions of higher learning, and laboratories of scientific institutions should be strengthened.

In the cities of the Ural Region there are four botanical gardens - two in Sverdlovsk, and one each in Perm and Ufa. Only one of these, in Sverdlovsk, carries on work on the effect of industrial pollutants on vegetation. At the present time, the Botanical Garden of the Institute of Biology of the Ural Branch of the U.S.S.R. Academy of Sciences carries on research along the following lines: a) studies of the physiological and anatomical resistance of woody plants to acid gases; b) selection of woody and flowering ornamental plants endowed with greater viability under conditions of industrial pollution; and c) means for improving soil conditions for plants growing on polluted areas (in cooperation with the Ural Institute of the Pamfilov Academy of Municipal Economy). These studies, which began 2-3 years ago (1961-1962), are of a rather limited scope. Moreover, a sizeable part of this work is carried on outside the basic science program of the Botanical Garden. The extent of this work must be enlarged.

In conclusion let us note:

1. Within the last few years, work has been undertaken in the Ural Region on the deleterious effect of industrial pollution on vegetation and on devising methods to overcome its results. Some of the institutions engaged in this work are: the Institute of Biology of the Ural Branch of the USSR Academy of Sciences and its Botanical Garden; the Ural Institute of the RSFSR Academy of Municipal Economy; the A. M. Gorki Ural State University: the Bashkir State University; the Sverdlovsk Institute of Labor Hygiene and Occupational Diseases; the forestry and landscaping organizations of Sverdlovsk and Perm

districts, and other institutions. However, these studies are largely fragmentary, are mostly concerned only with certain plant groups, and, what is most important, are conducted on none too high a scientific level.

2. The problem of plant protection against pollution is complex, and its solution is dependent on the analysis of the effect of various aspects of industrial pollution on plants, and on their subsequent synthesis in order to evolve a general theory of plant resistance.

To work out the theoretical bases it is necessary to attract a number of research institutions and to establish in the Ural Region a science center dealing with this urgent problem.

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THE DRAINAGE OF TEMPORARILY SWAMPED SOILS IN RELATION TO PINE PLANTINGS GROWING UNDER CONDITIONS OF INDUSTRIAL AIR POLLUTION

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During the last few years many pine stands have died in the Okhtinsk forest resort, bordering on the city of Leningrad. Extensive damage is done there to the conifers (a) by the smoke gases of the city's industrial enterprises situated near the forest and also (b) by swamping of forested areas. The damage was greatest among pine stands growing in areas of longleaf sphagnum moss* near the city limits. In similar pine stands at a distance from the city the amount of dead wood was smaller.

When areas of pine growing in longleaf sphagnum mosses within the zone of intensive air pollution were drained, the number of dead pine trees dropped sharply (Table 1).

Table 1

Distance from pollution source, m.	No. of square sections	Experimental plots	Distance from drainage ditch	No. of pines on experimental plots in 1960	No. of dead pines 1960-64	Dead pines by growth category, %			
						I	II	III	IV
300-1900 (1st experimental area)	12 (sections 15, 18)	a	0-20	256	44	11	15	51	23
		b	40-60	253	86	21	22	22	35
		c	60-100	254	141	24	26	19	31
1900-2650 (2nd experimental area)	38 (section 10)	d	0-20	250	32	5	9	51	35
		e	40-60	256	50	6	20	24	50
		f	60-100	258	65	20	30	25	25

With the drainage of pine stands in longleaf sphagnum areas distant from city limits (from 1900m. to 2650m.) the drop-off in the number of desicated pine trunks changes less radically.

To study the effect of drainage of soils having temporary excess moisture on pine stands exposed to industrial air pollution, experimental plots were laid out in the longleaf sphagnum area, three years after the drainage.

* [Translator's note: The Russian term used "dolgomoshnikov" is not too clear. Literally it means "of long mosses" and probably refers to long-sphagnum moss peats of the peat-bug soils.]

These experimental areas were subdivided into 20-meter-wide plots. On each such plot were no less than 250 recorded trees. During this study, the drainage ditches on the experimental plots were properly maintained.

The experimental plots were located in sections 15 and 18, and in squares 38, section 10.

Between 1960 and 1964 the dead trees on the experimental plots were counted. The results are summarized in Table 1.

The results showed that the number of dead pines increased with the distance from the drainage ditch. On experimental plot "a" the percentage of dead pines was 17.4, whereas on plots "b" and "c" the percentage was 33.99 and 39.76%, respectively.

The total number of dead pines in the experimental plots of the 2nd area, which was further removed from the sources of pollution, was smaller than in the 1st experimental area. Here, too, the number of dead trees increased with the distance from the drainage ditch.

On plots "c" and "f" located at a distance of 60-100m. from the drainage ditch, there is an appreciable increase of dead trees of the "growth category" I and II.

A morphological and physiological study was made of the pine needles, as well as an examination of the morphological symptoms of cones and seed and of the principal phisiological indices of the seed. The quantity of needles damaged by industrial smoke varied with the distance from the drainage ditch. The healthier needles were in all cases somewhat longer.

In the plantings that we investigated, the needles of trees growing near the drainage ditch, after being washed free of the dustlike industrial pollution, were dark green and, at times, gray-blue, while the needles of trees growing at a distance of 80-100 m. from the drainage ditch were light green. The same is true for pine regrowth. The needles on new branches on distant trees appeared in irregular clusters, whereas on trees near the drainage ditch the needles were evenly distributed.

The weight of the needles on experimental plots situated at a considerable distance from city limits was in all cases greater but even in these plots it increased with the proximity of the trees to the drainage ditch.

The lifespan of pine needles was also affected by the distance from the drainage ditch. The needles on trees in plots located 20-40 m. from the drainage ditch lasted for 2 years, whereas needles on trees in plots at a distance of 80-100 m. from the ditch stayed on the trees for 1 year only. Beyond the city limits, the pine needles on trees along the drainage ditch stayed for 3 years, whereas on trees at a distance from the drainage ditch the pine needles stayed for only 2 years. The decrease of the life span of needles, as well as their lesser weight and lesser abundance, are caused not only by the adverse effect of swamping of the plantings but also by the gradual accumulation of sulfur compounds in the pine needles until the cumulative effect of the sulfur compounds becomes lethal causing weakening and drop of needles.

Needles taken from trees growing at various distances from drainage ditches were analyzed in order to study the dynamics of sulfur accumulation in the mesophyll. The analyses showed considerable accumulation of sulfur in the needles (Table 2).

Table 2

Distance from source of pollution m.	Experimental plots	Distance from drainage ditch, m.	Percent of sulfur in tree needles (numerator: undamaged; denominator: with signs of damage)		
			1-year old	2-year old	3-year old
300-1900 (1st test area)	a	0-20	0.202 / 0.327	0.240 / 0.351	no needles
	b	40-60	0.233 / 0.347	no needles	" "
	c	60-100	0.244 / 0.396	" "	" "
1900-2650 (2nd test field)	d	0-20	0.186 / 0.343	0.207 / 0.346	0.303 / 0.393
	e	40-60	0.207 / 0.347	0.277 / 0.353	no needles
	f	60-100	0.234 / 0.361	0.260 / 0.377	" "
					&&&&&&&&&&&

It was found that the needles on trees growing near drainage ditches contain less sulfur than those on trees further away. Needles on trees growing on plots "d", "e", and "f" contained appreciably less sulfur than on trees growing on "a", "b", and "c". In all cases, the sulfur content of 2- and 3-year-old needles was higher than in 1-year-old ones.

Fifteen trees with approximately equally developed crowns and growing under similar conditions were selected on each experimental plot in order to study the effect of drainage on the fruit-bearing of pines growing on longleaf sphagnum-covered terrain. Cones were collected from the southern side of the middle section of the crown in the first days of February 1962. For each plot the collected cones (200) were graded according to color, size, shape, structure of seed wing, and the ratio of length to diameter. The distance from the drainage ditch did not greatly affect the color or the structure of the seed coat, or shell. There were some differences in the length, diameter, and weight of the cones. The results are presented in Table 3.

Pine cones growing on trees near the drainage ditch (0-20 m.) were generally larger and their average weight greater. No appreciable increase

Table 3

Distance from source of pollution m.	Experimental plots	Distance from drainage ditch m.	Average cone length cm.	Average cone diam. cm.	Average cone weight g.	No. of cones in 1 kg.
300-1900 (1st test field)	a	0-20	3.1	1.7	6.3	162
	b	40-60	2.1	1.3	4.8	217
	c	60-100	2.0	1.4	4.7	218
1900-2650 (2nd test field)	d	0-20	3.6	1.8	6.8	152
	e	40-60	2.2	1.3	5.0	193
	f	60-100	2.2	1.3	5.1	210

in size and weight was noticed in cones taken from trees at a distance of 40-100 m. from the drainage ditch. The effect of distance from the drainage ditch on the size and weight of cones taken from trees on the 2nd experimental area, which is further removed from the source of air pollution, is more pronounced. However, no significant increase in size and weight of these cones in comparison with those from the 1st experimental area was noticed at a distance of 60-100 m. from the drainage ditch.

The seeds in individual cones were counted by a modified G. N. Nezabudkin method. A skillet was placed on a gas ring and heated, then a cone was placed in it, and first turned on its side and then placed on its base. After one or two minutes the cone started opening and the scales, softened by heating, were readily picked with tweezers. Only fresh cones are suitable for this treatment, as the scales of dried cones are brittle and hard to pluck for seeds. Fifty cones from each plot were studied. The results are summarized in Table 4.

The number of seeds in cones from trees growing near the drainage ditch increased and the percentage of seedless cones decreased. The number of seeds in cones did not increase noticeably in samples taken from plots "b" and "c". However, the number of cones bearing no seeds rose. Also noticeable was an increase in the number of normally developed wings having no seed (up to 4%). The cones from pine trees on plot "d" in area 2 had a noticeable increase of seed, the number of seedless cones decreased. On plots "d" and "e" the normally developed wings having no seed amounted only to 1.5-2%.

Table 4

Distance from source of pollution m.	Experimental plots	Distance from drainage ditch m.	Percent of cones having number of seeds						Percent of cones without seeds
			3	5	7	11	15	24	
300-1900 (1st test field)	a	0-20	10	14	10	22	24	4	16
	b	40-60	16	22	16	12	12	-	22
	c	60-100	17	21	16	11	11	-	24
1900-2560 (2nd test field)	d	0-20	4	10	12	21	23	18	12
	e	40-60	7	6	16	31	16	8	16
	f	60-100	7	7	27	21	15	-	23

An increase in the number of seeds and a decrease in the percentage of seedless cones taken from trees on plots "d" and "e" in the 2nd area, which is farther from city limits, is the result not only of the effect of drainage but also a result of the decrease of the degree of the adverse effects of the industrial discharge.

In the 1st area, 150 cones contained 945 ripened seed, or an average of 6.3 seeds per cone. Cones from the 2nd area yielded 8.3 seeds per cone. The seed content of cones varied greatly - from 0 to 24. Cones from the 1st area contained up to 8.6% empty seeds, while cones from the 2nd area contained up to 6.1%. As the distance from the drainage ditch decreased, the number of empty seeds declined 1.5-2.4%.

In the 1st area, the number of cones from some trees growing near the drainage ditch increased. In the 2nd area, no difference could be observed in the number of cones on trees growing either adjacent to the drainage ditch (0-20 m.) or at a distance from it. It is, therefore, permissible to conclude that draining excessively moist forest areas is most beneficial to the fruit bearing of those pines which grow in areas polluted by industrial exhausts.

No special regularity was noticed in the length and width of seeds collected from various experimental plots. There was some difference in the weight of seed and also in some of the most characteristic physiological indices of the sowing quality of the seed, depending on the proximity of pine trees to the drainage ditch. The results are shown in Table 5.

Table 5

Experimental plots	Distance from drainage ditch m.	Weight of 1000 seeds g.	Percent of absolute germination	Sprouting vigor in 7 days, %
a	0-20	6.3	98.2	65.2
b	40-60	5.6	97.3	63.8
c	60-100	5.1	96.2	63.1

Our data indicate that the weight of 1000 seeds from trees growing near the drainage ditch increases. Also, the germination and the vigor of seed sprouting increase somewhat. The average rest period of all the studied seeds was 7.4 days.

In summarizing the results of our observations it can be concluded that the effect of polluting gases of the same concentration and duration will affect pine trees differently, depending on the changes in the soil moisture conditions.

Three years after drainage, the adverse effect of smoke decreases. This is expressed in the decrease of the intensity of sulfur accumulation in the pine needles, in the increase in the weight of the needles, cones and seeds, as well as in the increase in the growth of needles and in the improvement of the most characteristic physiological indices of the seed.

THE EFFECT OF INDUSTRIAL SMOKES AND GASES UPON CONIFEROUS FORESTS GROWING UNDER CONDITIONS OF INCREASED HUMIDITY IN THE MOSCOW REGION ("PODMOSKOV'E")

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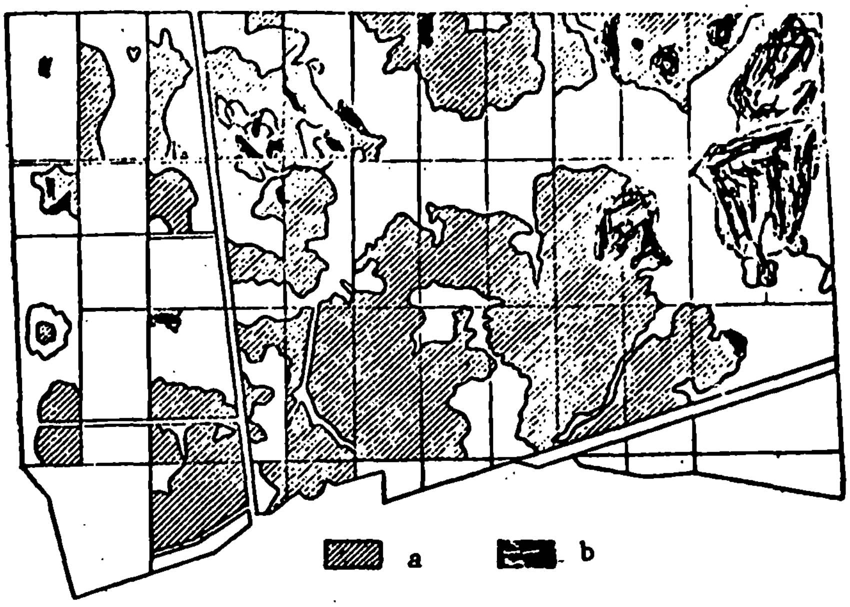
In the journal "Lesnoe Khozyaystvo" No. 7 for 1960, E. V. Lugovoy published an article, "The Influence of Gases and Dust on Coniferous Plantings in the Moscow Region". The author considered that the increase of moisture in the air, as a result of the introduction and the utilization of water reservoirs in Moscow, had a favorable effect on the growth of forest species and neutralized the adverse effects of industrial smokes and gases on forest vegetation, including the coniferous species. In particular, he indicates that the common pine trees do fairly well in Moscow in the vicinity of the factory "Krasnyy Bogatyr'". However, the Commission to Investigate Moscow City Parks of Culture and Recreation (Sokol'nicheskiy and Izmailovskiy) by 1949 came to the conclusion that the basic reason for the destruction of woody vegetation, mainly coniferous species, is the adverse effect of industrial gases ("Work of the Scientific-Technological Commission ...", 1949). Meanwhile, the Moscow lake and Moscow's main reservoirs, created with watershed water (Khimkinskoe, Kliaz'minskoe, Pialovskoe, Uchinskoe, and Ikshinskoe), were already filled with water in 1937 and partially so in the subsequent three years. This, however, did not have any noticeable effect on the condition of the tree plantings in Sokol'nicheskiy and Ismailovskiy parks. In Sokol'niki an insignificant number of old pine trees were left only in the northern part of the park. According to data of the head forester L. A. Kashcheev, in the general area of Izmailovskiy Park, which extends over 1180 hectares, 120-year-old common pines occupied in 1931 65% of the forest-covered land area (34 sections out of 39). Many of the forest sections there were entirely covered by the common pine. In the park at that same time, an intensified replacement of pine by linden was noted. Thus, from 1931 to 1954, in the central part of the park, closer to the city and to industrial enterprises, the area of pine repopulation decreased by 85.96 hectares, and, in the part of the forest more removed from the city, by 30.39 hectares. At that time there occurred also a massive desiccation of firs, and the area they covered was reduced during that period by 63%. A definite correlation between the destruction of pines and their distance from industrial enterprises was noted. Thus, at a distance of 2km from factories the decrease in pines per hectare consisted of 97 m^3 of timber, but at a distance of 5km it was 23.4 m^3.

The Commission of the Central Administration of Forest Economy and the Field-Protection Planting, having conducted in July 1955 an investigation of the desiccated plantings in the Moscow region, found that in the industrial regions of Balashikh, Sokol'niki, and in the Izmailovskiy Forest, a massive loss of trees took place (30-40 m^3 per hectare), while in similar pine stands of Malakhovskiy and Sosnovoborskiy Forests, further from the factories and mills, the annual loss of trees was insignificant (1-2 m^3 per hectare [Timofeev, 1956]). The map of Izmailovskiy Forest, published from material of the Fifth Moscow Aerial Photo, Forest Structure Expedition, graphically shows the dynamics of change of the areas over 13 years (c. 1946-1959). Pine plantings are, however, well preserved in the north-eastern part of the park, a part most remote from the industrial enterprises (see figure).



Change in areas under pine plantings
in Moscow's Izmaylov park:

a - 1946; b - 1959

The accumulation of sulfates, by the assimilating mechanism (Bredemann, 1933; Pelz, 1959), is one of the verified symptoms of damage to plants from sulfur dioxide. Analysis of coniferous needles of trees that grew up in the neighborhood of a large industrial complex showed that at a distance of 2 km in the direction of prevailing winds they contain 0.63% sulfur; at a distance of 3 km, 0.54%; at 4 km, 0.36%; and at 9 km, 0.08% (Riazanov, 1954). Analogous data were obtained from the analysis of the needles of thorny firs in various regions of Moscow and its environs (Abramashvili, 1957), and also in our study of the reasons for the massive destruction of pine trees in the Cheliuskintsev cultural and recreational park in the city of Minsk, which is situated in the direction of the prevailing winds, about 2-5 km from heavy industrial enterprises emitting a significant quantity of smoke and gases.

In view of the report by M. S. Gol'dberg (1949) (Table 1), it is impossible to consider the increase of humidity as a factor conducive to air purification.

Table 1. The effect of humidity upon the concentration of atmospheric pollutants (according to Gol'dberg, 1949)

Pollutant	Change in intensity factor	Effect upon pollutant concentration
SO_2	Fluctuations of air humidity	No effect upon concentration.
	Cloudy weather	Clear cut rise.
	Fog	Sharp, large increase.
	High humidity and fog	Concentration increases, dispersion slowed down.
	Rain	No noticeable effects.
CL_2	Relative humidity raised from 50 to 98%	Concentration decreases, number of positive tests drops.
Soot	Fluctuations of air humidity	No connection observed.
	Cloudy weather	Concentration increases.
	Fog, calm	The same.
Dust	Increased humidity	Increased concentration of suspended dust.
	Fog	Concentration of suspended dust increases 2-4 times over normal.
	Rain (screened according to Lifman-Lizechang)	Sharp increase in number of dust particles on horizontal plates during first day of rain and a decrease in the following days; increase occurs due to an increase in soot particles.

The concentration of contaminants in the air (except Cl_2) are most sharply increased during fog. Observations carried out in the Urals showed a direct dependence between the concentration of soot and sulfur dioxide, on the one hand, and the humidity of the air, on the other (Riazanov, 1957).

Thus, many investigations have shown that with the increase in humidity there is an increase in the concentration of damaging smoke and gases. These concentrations can often reach toxic proportions, sufficient to cause not only chronic damage invisible to the eye, but also a sharp toxic effect leading directly to the destruction of the plants. For example, in lowlands, where the fog hangs on, the sharp toxic effect on green foliage from the anhydrides of sulfuric and sulfurous acids in sufficiently strong concentrations (Kuz'min, 1950) can be observed. With the rise in temperature as well as with an increase of humidity in the air and an increase in the amount of precipitation the process of forest desiccation is increased (Il'iushin, 1953).

In drought years, sulfurous anhydride causes less damage to plants than in wet years (Lent, 1959). The increase in humidity is not only conducive to the formation of acidic fogs, but also prevents the closing of the stoma. The latter creates conditions which are beneficial for the penetration into leaf hollows of air saturated with acidic gases. Plants that have wilted are more resistant to the effects of sulfur dioxide (Kroker, 1950), while the limited consumption of water increases; for example, the resistance of tomatoes to "smog" damage, i.e., to fog saturated with hydrocarbons and oxidants, characteristic of Los Angeles (Koritz and Went, 1953).

Earlier observations by foreign investigators had already established that humid and foggy weather increases the damage to plants by the smoke gases of metallurgical works. These observations were confirmed by experimental methods (Holmes, Franclin, and Gould, 1915) and extended to other acid smokes (Cristiani, Gautier, 1925). It was established that the main damaging effect was caused by acid gases in dissolved form.

Experimental studies have shown that the moist parts of plants are more quickly damaged than the dry parts, not only by more soluble acidic gases such as hydrogen fluoride but also by sulfur dioxide.

However, Zimmerman and Hitchcock, 1956, having carried out experiments on approximately 40 species of plants for their comparative sensitivity to sulfur dioxide and hydrogen fluoride, found no visible correlation between the quantity of stoma and sensitivity. A deposit of soot and smoke leads to the loss of illumination, and this causes the paling of chloroplasts and a decrease in the productivity of photosynthesis (Krasinskiy, 1950). Thus, the negative effect of soot and smoke on plants is not subject to doubt.

It is difficult to study the physiological effects upon plants of fog-borne sulfuric acid and vapors of sulfuric acid and sulfur trioxide (SO_3) because these substances are ordinarily found in the air along with sulfur dioxide, and their isolation is quite difficult. However, to consider the anhydride of sulfuric acid harmless, as does engineer E. V. Lugovoy (1960), is without justification. More than that, the massive poisoning of the population, which has been observed in a number of industrial regions in Belgium (in the Maas valley - 1930), in the USA (the city of Donor - 1948), and in England (London - 1952) in periods of stable, anti-cyclonic weather with temperature inversion and fog, has been ascribed by some authors to the joint effect of aerosols of sulfuric acid and sulfur dioxide, as a result of which the overall toxic effect is increased (Ryazanov, 1957). Characteristically, a sharp increase in sulfuric acid content of the air is observed during fogs.

At the present time, data are being received indicating that sulfurous anhydride is most dangerous in the presence of water vapor and surface-active dust, particularly soot, when it oxidizes into sulfuric anhydride and forms sulfuric acid. This concurs with the higher resistance of plants in dry weather. The toxicity of sulfur gases is to some degree also increased if carbon monoxide, with admixtures of aldehydes and especially ozonides, are present. The toxicity of sulfur gases is greatly increased by the presence of nitric oxides (Lent, 1959).

Ammonia and sulfur dioxide are the constant byproducts of widely distributed types of industry. Ammonia is given off during the process of making fertilizers, nitric acid, ammonium salts, and during the dry distillation of coal, etc. Hydrogen sulfide is given off during the processing of inorganic sulfur compounds from oil refining processes, from the manufacture of artificial silk, etc. Even more so, it is impossible to consider incidental the sulfurous anhydride that occurs under industrial conditions wherever there takes place burining of substances containing sulfur: in non-ferrous metallurgy (the smelting of copper, zinc, nickel, etc.) and in fuel-power plants that burn coal and fuel oil. The following data give an idea of the amount of contamination in these cases. For example, the TETs-3 (heat and electric power plant) in Minsk daily emits into the atmosphere such a quantity of sulfurous anhydride that it is the cause for the massive dying of the pine trees in the Chelyuskintsev cultural and recreational park, which is located 5 km from the source of emmission.

The metropolitan parks in Sokol'niki and Izmailov are in good condition only because during the course of more than twenty years, the susceptible plants were replaced with more gas-resistant ones. But for these measures, many areas (in these parks) would now be wastelands unfit for the recreation of the working people.

Concrete measures for the preservation of valuable forest stands around industrial centers of the country can be planned only in the course of many years of scientific investigations that take into consideration the effects of different industrial enterprises in relation to the kind and quantity of their waste discharge, and in relation to other ecological factors as well as the biological peculiarities of different species of plants.

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SOME PECULIARITIES OF THE SUSCEPTIBILITY OF SCOTCH PINE SPROUTS TO SULFUR DIOXIDE INJURY

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Among specimens of a given botanical species there occur a large variety of morphological variations and biological peculiarities as well as differences in physiological-biochemical indices and in chemical composition. These intraspecific differences may, directly or indirectly, condition dissimilar resistance of the individual plants to unfavorable external environmental conditions. It is well known that biotypes exist which are more or less resistant to high soil salinity (Strogonov, 1962) or more or less frost-resistant, etc. In the verdant plantings of many industrial cities of the Urals we have observed in lilacs, poplars and other species, a differentiation of plants in the degree of their susceptibility to injury from toxic gases. In addition, V. Kroker (1950) presents data indicating that individual varieties of garden roses are more resistant to mercury vapor than others. However, data on intraspecific differentiation of plants according to the degree of gas resistance are very scarce, although such data would be of great scientific and practical interest. For example, the lack of records concerning intraspecific variability may possibly explain the numerous discrepancies in scales of various authors when evaluating the degree of gas resistance of a number of species. In light of the above, we have endeavored to clear up certain aspects of plant variability in relation to the degree of their gas resistance. Experiments were carried out to determine the effect of sulfur dioxide on the sprouts of pine seeds that were obtained from different maternal specimens. These were taken from plants growing together in the pine forest of Chaykovskiy industrial forest administration of the Perm region. For the germination, the seeds used were from cones collected near the middle part of the tree crowns. The germination tests were carried out on filter paper in petri dishes, during a period from the 14th of August to the 14th of September, 1964. Into each dish were placed 50 seeds. Thirty-day-old pine sprouts were subjected to fumigation with sulphur dioxide in a gas chamber for a period of 17 hours (from 4 p.m. on the 14th of September to 9 a.m. the 15th of September). The initial concentration of gas was made up earlier and was balanced out at 1.62×10^{-5} [Tech. Ed.'s Note: No units given for this quantity.] of sulfur dioxide by volume. The degree of injury was estimated according to the percentage of the yellowed part of the cotyledon: $\Pi = \frac{l_1}{l_2} \times 100\%$ where l_1 is the length of the yellowed part of the cotyledon in millimeters, l_2 is the overall length of the cotyledon, and Π is the percent of injury.

From data reported earlier (Kroker, 1950; Nikolaevskiy, 1964), it is known that the water supply to a plant plays an important role in gas resistance. A worsening of conditions of water supply affects the dynamics of the types of water in the plant, as well as the stomatal apparatus of leaves (Alekseev, 1948) which in turn is reflected in the gas resistance of the plant. For a clarification of the role of the water regime in our experiments, part of the plants were subjected to fumigation with sulfur dioxide at the same concentration for a period of 17 hours after drying for two days following cessation of watering.

As shown in Table 1, there is no definite correlation between the morphophysiological characteristics of the parent tree, and its seed, and susceptibility of the sprouts to gas injury.

The only correlation established was that of an inverse correlation of susceptibility to gas injury and the degree of development of the sprout. For example, the correlation coefficient, r, of the length of the cotyledon and the degree of damage for family No. 7 is 0.18, for No. 11 it is 0.24, and No. 12 is 0.26, while the ratio r/m_r was the same from 0.8 to 1.5.

Within the limits of one family a great variability of injury of the sprouts was observed as a result of their unequal conditions, different micro-environments, and, perhaps, also due to genetic segregation. Therefore, the coefficient of variation, C, for the entire group reaches a magnitude of 39.6%, and within the limits of the separate families the value was even higher (tree No. 7, 42.7% and tree No. 12, 81.8%). It can be supposed that a considerable variation in extent of injury, both in the sum of all lots and within the limits of the families, depended on the degree of development of the plant. The larger plants generally were more resistant to sulfur dioxide, while the progeny of one family varies greatly in resistance depending on the size of the seedlings. In connection with this, it was observed that an inverse correlation existed between the extent of injury and the size of the cotyledon (within each family).

Water provision also influences the degree of injury to the sprouts. An experiment, carried out with the same plants, showed a decrease in seedling damage of around 15.8%, if the sprouts had not been watered for the previous two days. Additional experiments are necessary to elucidate the reasons for the water effect. It is possible that individual differences in moisture provision, as well as in the vigor of seedling development, may be responsible for differences in resistance to sulfur gas exhibited by different families. On the other hand, a worsening of the condition of water supply results in a decrease of the degree of stomatal openings, which could also affect the susceptibility of the sprouts to gas injury (Alekseev, 1948; Nikolaevskiy, 1964).

Of considerable interest is the mechanism of the action of harmful gases on the pigments of the plants. Insofar as it has been reported in the literature (Krasinskiy, 1950; Noack, 1924; Jahnel, 1954), in the green plants the pigments are among the first ones to be affected by acidic gases. Hence, a study was made of the content of the various pigments in the cotyledons of

Table 1

Characteristics of pine sprouts obtained from seeds of various trees and sulfuric anhydride damage in relation to experimental variables.

(I - without drying the sprouts, II - with drying)

Number of the trees	Measurement of the trees		Fruiting	Average weight of one seed (milligrams)	Coloration of the seeds*	Germination of the seeds		Average number of cotyledons on one sprout		Average length of cotyledon (millimeters)		Average length of damaged parts of cotyledons (millimeters)		Damage of the length of the cotyledon in %	
	height (meters)	diameter (centimeters)				I	II	I	II	I	II	I	II	I	II
2	24	33	Strong	5.58	BB	72	92	4.90	5.70	16.1	14.9	4.07	4.97	26.6	33.2
7	22	28	Weak	5.63	MB	56	38	5.10	4.62	17.8	19.4	3.92	4.10	22.0	22.1
9	26	26	Strong	4.61	BB	86	96	5.42	5.50	18.7	18.5	7.82	2.42	41.7	13.0
11	26	37	Weak	5.22	BB	42	36	4.97	4.82	16.8	18.5	12.07	11.40	71.2	62.8
12	26	35	Strong	4.68	Br	58	48	5.50	5.50	15.0	13.6	6.37	4.47	42.5	34.0
17	26	32	Average	5.54	G	34	38	5.47	5.60	16.5	16.6	7.25	2.48	43.9	15.4
18	27	42	Weak	4.83	Br	92	82	5.64	5.20	18.9	19.4	6.87	5.20	36.4	28.2
22	28	38	Strong	4.42	Bl	88	76	5.10	5.48	14.5	15.5	9.90	3.06	68.2	18.4
32	27	32	Strong	5.85	G	70	76	6.03	6.13	18.9	21.7	5.08	2.24	26.9	10.3
34	26	30	Very strong	4.31	Bl	90	84	5.65	6.14	17.2	16.3	6.22	3.33	36.2	20.5
			Average			68.8	66.8	5.38	5.46	17.0	17.4	6.95	4.36	41.6	25.8

*Abbreviation meanings: BB - black-brown, MB - motley-brown, Br - brown, G - gray, Bl - black pine sprouts that were fumigated with sulfuric acid vapor for 17 hours, as well as of the sprouts of the controls. The results of the experiment are shown in Table 2.

As a result of the effect of the sulfuric acid fumes, the main damage was done to the upper part of the cotyledon. In an average injury of the length of the cotyledons (30.8%) chlorophyll A and B were completely destroyed, in the damaged as well as in the undamaged part. The same occurred with carotene. In the damaged part of the cotyledon, violaxanthin was also totally destroyed, while in the undamaged portion only about one-half (56.7%) of it was destroyed. In both parts of the cotyledon chlorophyll A and B were changed into phaeophytin, a band which was well delimited on chromatograms. Similar reports may be found in the literature (Krasinskiy, 1950; Jahnel, 1954) on the conversion of chlorophyll into phaeophytin under the influence of acidic gases.

According to the data of several authors (Sapozhnikov, 1937, 1963; Eydel'man, Khodzhaev, 1963), xanthophylls are formed upon oxidation of carotene. Since we did not observe an increase in xanthophylls, we can surmise that if a transformation of carotene into xanthophyll occurred; than some of the forms of xanthophyll are also subject to oxidation. This was apparent in the case of violaxanthin: in the damaged part of the cotyledon it was not detected, but in the undamaged part it remained at 56.7%. Evidently, a greater oxidizing capacity resulted in the above phenomenon as a consequence of sulfuric acid fumes.

As a result of the influence of the sulfuric acid fumes, the ratio of chlorophyll A to chlorophyll B, carotene to xanthophyll, and chlorophyll to carotene decreased and approached zero, but the ratio of lutein to violaxanthin increased. Consequently, under the influence of strong oxidants in plants, first chlorophyll A and B are destroyed; from among the carotenoids - - the most reduced was carotene, and from among xanthophylls - violaxanthin. The most resistant is lutein, possibly due to additional transformation of violaxanthin into lutein upon oxidation (Popova et al., 1964; Sapozhnikov et al., 1962).

Conclusions

1. A variability of gas resistance of 30-day-old pine seedlings to sulfur dioxide was determined both for the entire group of plants as well as within the limits of separate families. One of the causes of the differential plant damage by sulfur dioxide was found to be due to differences in the micro-environment of the habitat (i.e., water availability) and probably, individual peculiarities of the organism.

2. Under the influence of sulfuric acid fumes, in cotyledons of pine sprouts, chlorophyll A and B are converted to phaeophytin, carotene is entirely destroyed, and violaxanthin is partly destroyed. The most resistant to the action of sulfuric acid fumes is lutein. Neoxanthin is less resistant than lutein.

Table 2

The content of pigments in cotyledons of the pine tree which have been fumigated by sulfur dioxide.

Pigments and their correlation in cotyledons	Before fumigation	After fumigation	After fumigation, % of the control
	milligrams in 1 gram of raw moist weight		
Upper half of cotyledon			
Chlorophyll A	0.457	0	0
Chlorophyll B	0.245	0	0
Carotene	0.013	0	0
Xanthophylls:			
Lutein	0.112	0.116	103.5
Violaxanthin	0.102	0	0
Neoxanthin	0.091	0.083	91.0
Ratio:			
Chlorophyll A to Chlorophyll B	1.86	0	-
Carotene to xanthophyll	0.04	0	-
Lutein to violaxanthin	1.09	∞	-
Chlorophyll to carotene	2.21	0	-
Lower half of cotyledon			
Chlorophyll A	0.463	0	0
Chlorophyll B	0.206	0	0
Carotene	0.021	0	0
Xanthophylls:			
Lutein	0.093	0.091	97.7
Violaxanthin	0.067	0.038	56.7
Neoxanthin	0.119	0.064	53.8
Ratio:			
Chlorophyll A to Chlorophyll B	2.24	0	-
Carotene to xanthophyll	0.07	0	-
Lutein to violaxanthin	1.39	2.40	-
Chlorophyll to carotene	2.23	0	-

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GAS RESISTANCE OF PINE AND BIRCH

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Under the conditions prevailing in the industrial areas of the Urals, the study of smoke resistance of plants and, above all, of trees, is motivated not only by the interest in landscaping of industrial and residential areas but also by the needs of forestry. The withering of coniferous mountain forests, primarily of pine stands, on tens of thousands of hectares, caused by smoke from factories, poses an urgent problem of forest restoration. However, the severe climatic and the unique forest-growing conditions of the mountain slopes of the Urals greatly limit the number of species of trees and shrubs capable of forest formation. Because of this, in the selection of smoke-resistant species of trees and shrubs, the major attention must be devoted to the local tree flora. In the present work we shall analyze the gas resistance of the European white birch and Scotch pine in the environs of the city of Karabash and its copper smelter.

The natural conditions of the eastern foothills of the Southern Urals favor two species as forest plants on its mountain slopes: the Scotch pine and the European white birch. Birch-pine forests covering the foothills were designated by B. P. Kolesnikov (1961) as characteristic for the mountain forest areas of the East Ural Province where Karabash is located. The European white birch and the pine are characterized by many authors (Krasinskiy, 1937; Krasinskiy and Knyazeva, 1950; Kuntsevich and Turchinskaya, 1957; Vanifatov, 1959) as being highly susceptible to gas and incapable of growing in smoke-polluted areas. Yet, some other investigators (Ilyushin, 1953; Bulgakov, 1961) suggest the possibility of using the birch for the purpose of making verdant smoke-polluted areas. N. G. Krotova (1957, 1959) considers almost all the major forest trees, with the exception of pine, suitable for reforestation of smoke-contaminated areas in the surroundings of Moscow.

Such contradictions in assessing smoke resistance of trees can be explained to some degree by the differences of regimen, i.e., the pattern of occurrence and the nature of smoke pollution in the different areas investigated. Indeed, under conditions of constant or prolonged minor smoke pollution with a sulfur dioxide concentration of less than 1 mg./m.^{3}, all deciduous species are found to be gas-resistant, whereas coniferous species with perennial needles suffer severely and wither, as a result of the detrimental cumulative effect of sulfur compounds, which gradually accumulate in the perennial needles. Under conditions of periodic, strong gaseous attacks of short durations, with a sulfur dioxide concentration of 30-50 mg./m.^{3} or more, the leaves of all species drop. The ability of a species to survive is related to the ability of its defoliated shoots to withstand the adverse environmental factors and the ability to renew their foliage next season.

Westerly winds prevail in the areas of the Urals under consideration. Inasmuch as wind carries the smoke, the areas located northeast, east, and southeast from the industrial enterprise can be considered as permanently smoke-affected, whereas the areas located south, west and north of the plant are subject to intermittent smoke attack. Investigations have shown that the permanently smoke-affected area, which includes the so-called "Zolotaya Gora" (the Karabash forests of the Kyshtym Forest Reserve), is completely deforested. Thirty to sixty years ago, the local pine stands were subjected to clear-cutting to satisfy the needs of the gold mines, the copper smelter, and of the local population. The heavy damage to the pines caused by smoke from the smelter was among the reasons for clear-cutting of the forests. In the years that followed, heavy smoke pollution slowed down and hindered the revival of forest vegetation. The western slopes facing the smelter are also devoid of grass cover. Only the following sparsely growing plants were recorded: sweet william, purple stonecrop, garden burnet, bittersweet, yellow bedstraw, clover lupine, drug Solomon's-seal, low meadow rue, quack grass, reed grass, and others. On the less smoke-affected eastern slopes, in areas where fresh soils are found, bunches of quack grass and reed grass covering not over 30% of the area and growing up to 40 cm. in height develop on gently sloping ground. It is only at the foot of the eastern slope that there begin to appear solitary specimens of European white birches.

In the area of intermittent smoke, the picture is quite different. In places where pines were subjected to clear-cutting twenty years ago there appeared white birches, which at the present are 17-20 years old. Their height varies from 4 to 6 meters and their close stand is 0.5-0.7 m. The ground vegetation covers 30-50% of the area and includes slender and Kentucky bluegrass, reed grass and chee reed grass, clover lupine, northern bed-straw, blueberry, libanotis, and others. The wide distribution of the European white birch under these conditions is attributable to ecological factors.

It should be noted that in the birch groves, located west of the smelter, blighting by gases occurs as a rule in the second half of the growing stage (July-August). During this period, the weather is often stormy with frequent rain, low barometric pressure, and variable winds. By this time, birch shoots have completed their growth; and the formed buds are well-adapted to the late summer and fall-winter season and have a high drought and frost resistance.

According to the "Miassovo" meteorological station (Zharikov, 1959) located in the Ilmen nursery near Karabash, July has an average precipitation of 98 mm. or around 20% of the total annual precipitation. In some years, July precipitation amounts to 30% of the annual. The average for May is 48 mm. or 10%; for June, 57 mm. or 14%; and for August, 59 mm. or 12.4% of total annual precipitation. It should be noted that in July there occur heavy and long-lasting rains accompanied by sharp drops in barometric pressure and by northerly and easterly winds. It is during this very time that the smoke hovers close to the ground and affects the vegetation.

In clear weather of anticyclonic type with high barometric pressure, the gases emanating from the smelter stacks rise upwards and gradually dissipate in the air. Even if these gases do reach forests and ground vegetation at considerable distance from the smelter, their concentration is so small as to be harmless. During cyclonic weather accompanied by rain, the noxious gases hug the ground and thereby destroy vegetation. Even though the birch crown be gravely damaged and prematurely defoliated, the birch begins its normal growth the next season and the leaves unfold from the buds which survived through the winter. Table 1 gives the characteristic growth of European white birch standing 2 km. southwest from the smelter and gravely (70-100%) damaged by sulfur dioxide in the second half of summer for the last three consecutive years. One can assume that the crown of the birch was damaged also in other years. In spite of that, there are no dead branches in the crown and the growth of the current year is satisfactory.

Table 1: Characteristics of a typical 19-year old European white birch repeatedly damaged by sulfur dioxide during the second half of summer (July)

Height of trunk, m. / Trunk diameter (at 1.3 m.) cm.	Diameter of crown, m. / Height of crown start m.	Height of increment of trunk, cm.				
		1961	1960	1959	1958	1957
5.5 / 5.6	1.5 / 0.3	24.5	8	27	20	13

It should also be noted that in some years, e.g., in 1960, gas attacks on vegetation in the westerly direction occurred also in June, at the time when the growth of the shoots was not yet complete, and the buds were not completely formed. Inspecting a damaged plot located in compartment 38 of the Agardyash forest of the Kyshtym Reserve in 1961, it was found that the crown of damaged birches withered. It was noticed that in birches severely damaged by gas abundant new growth sprouted on the lower part of the trunk of trees. In years when birches were severely damaged, they showed no "biological gas resistance" (a term used by N. P. Krasinskiy 1937-1950), i.e., they did not develop new leaves immediately following the damage to their crown. This may be related to the fact that the summer climate in this part of the Urals is less favorable then in the central belt of European U.S.S.R. where Krasinskiy conducted his investigations.

The pine is capable of gas resistance similar to that of the birch. The pines in compartment 49 of the previously mentioned Reserve, occasionally affected by gases, can serve as an example. In July 1960, vigorously growing 6- and 13-year-old pines, hitherto free of gas injury, were severely damaged by sulfur dioxide. However on trees with healthy root systems and fully formed buds, the remaining coniferous needles (Tables 2 and 3) were sufficient to make possible normal sprouting in 1961. Thus, the pine after a single, severe gas injury in the second stage of its vegetation, accompanied by the loss of a considerable part of its foliage, is capable of renewing its growth next season provided its buds survived during the winter.

Table 2:

Characteristics of typical 6-year-old pines damaged by sulfur dioxide in July 1960.

Tree no.	Height, cm. / Trunk diam. cm.	Year of trunk increment	Increment cm.	Extent of damage to needles, %
1	60 / 1.9	1961	8	0
		1960	3.5	100
		1959	16.0	0
		1958	9	0
2	63 / 1.3	1961	14	0
		1960	23	95
		1959	7	77
		1958	11	-
3	82 / 3.2	1961	11	0
		1960	15	90
		1959	14	0
		1958	22	0
4	84 / 3.1	1961	18	0
		1960	32	68
		1959	13	0
		1958	15	0
5	104 / 2.3	1961	15	0
		1960	40	71
		1959	13.5	0
		1958	13	0

Table 3:

Characteristics of typical 13-year-old pines damaged by sulfur dioxide in July 1960.

Tree no.	Height, cm. / Trunk diam. cm.	Year of trunk increment	Increment cm.	Extent of damage to needles, %
1	190 / 5.6	1961	54	0
		1960	49	75
		1959	16	11
		1958	21	--
		1957	25	--
2	195 / 4.5	1961	18	0
		1960	50	67
		1959	27	36
		1958	30	-
		1957	16	-
3	250 / 6	1961	48	0
		1960	57	65
		1959	43	27
		1958	35	28
		1957	42	-
4	256 / 6.2	1961	40	0
		1960	55	58
		1959	46	46
		1958	40	-
		1957	40	-
5	267 / 6.4	1961	55	0
		1960	54	14
		1959	66	10
		1958	16	-
		1957	26	-

The data on smoke resistance of birch and pine, quoted in this paper, do not fit in with the widely accepted views advanced by N. P. Krasinskiy and his co-workers (1937-1950). As is known, N. P. Krasinskiy suggests three types of gas resistance: physiological, morpho-anatomical, and biological. The physiological gas resistance is determined by the physiological and biochemical properties of the plant, while the morpho-anatomical is determined by those structural elements of the leaves which control gas exchange and, consequently, the penetration of gases into the mesophyll. The biological gas resistance consists of the ability of plants to renew rapidly parts and organs damaged by gas and thus, regain their ornamental aspects. N. P. Krasinskiy emphasizes that this type of gas resistance is characteristic of rapidly growing trees and shrubs. E. I. Knyazeva (1950) asserts: "...when speaking of biological gas resistance it should be remembered that its extent is not constant for any one species. Biological gas resistance can be strong in the first half of summer and then drop to almost nothing by the end of summer. This is explained by the cessation of growth of our trees and shrubs in the second part of summer. Plants continuing to grow until autumn retain their biological gas resistance to the end of the growing period. Because biological gas resistance is tied to the plant's ability to sprout rapidly new leaves and shoots to replace the damaged ones, it depends in large measure on the rate of growth. The latter is in a sense an index of biological gas resistance."

Without stopping to analyze the first two types of gas resistance, let us consider the so-called biological gas resistance in an ecological frame of reference. It is clear from the above that a species capable of rapid regeneration of its foliage during the same growth stage is endowed with high gas resistance, whereas species devoid of this ability have a low gas resistance. From this point of view, N. P. Krasinskiy and E. I. Knyazeva consider box elder, poplar, birch, barberry, and alder buckthorn endowed with appreciable gas resistance. Because of it, box elder is considered as a completely gas-resistant plant and is recommended for planting in strongly smoke-affected areas, notwithstanding that its foliage is severely damaged by sulfur dioxide. From this point of view, the conifers, e.g., pine, spruce, and fir, are considered totally unsuitable for planting in such areas, because of their lack of biological gas resistance, although their needles, because of their anatomical and morphological characteristics, are but slightly affected by sulfur dioxide.

Our observations show that in conditions prevailing in the eastern foothills of Southern Urals, the birch is devoid of the so-called biological gas resistance. Defoliation of birches by gases in the first half of the summer leads to withering of the crown during summer drought or during severe winter conditions. Birch groves located west from the source of smoke are as a rule subject to smoke damage in the second half of their growth stage when they are devoid of leaves and display a high drought and frost resistance; this explains the successful growth of birches under conditions of intermittent gas attack. Therefore, the faster the completion of growth of shoots and the formation of buds in the crown, the higher is the resistance of the tree. Thus, of special interest are littleleaf linden and Siberian pea shrub, both having a short growth period and a high drought resistance of the shoots. Extended growth of shoots does not contribute to greater resistance of plants in the Ural region under discussion, because severe winter conditions kill these shoots, although they may show a greater biological gas resistance during the vegetative season.

Conclusions

1. Gas resistance of woody plants depends in great measure on the forms of smoke pollution and on local climatic conditions. The smoke injury to forests and their destruction under the conditions existing in the Southern Urals is intimately connected with the zonal climatic conditions, and, above all, with the weather during the growth season.

2. Two of the most important forest forming species - European white birch and partly Scotch pine - can thrive satisfactorily under conditions of intermittent severe gas attacks of short duration. Their gas resistance is conditioned by the occurrence of these attacks in the second half of the vegetative season. Normally, rainy weather, together with changeable winds and low barometric pressure, occurs in July and pushes the noxious gases down close to the ground.

3. The growth and formation of shoots is almost complete during May and June; the absence of the so-called biological gas resistance but high drought and frost resistance of defoliated birch and pine shoots insures their viability in late summer, autumn and winter, and resurgence of vegetative processes the following season.

4. In Karabash, for green plantings located to the south, west and north of the smelter European white birch should be considered most important. For aforestation of the mountain slopes littleleaf linden and Siberian pea shrub may be used.

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THE EFFECT OF SULFUR DIOXIDE ON WOODY PLANTS UNDER THE ENVIRONMENTAL CONDITIONS PREVAILING IN THE SVERDLOVSK REGION

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An important aim in the investigation of the effect of various gases on plants is to study the physiological and biochemical reasons for the different degrees of resistance of plants to these gases, as well as to reveal and to ascertain the type of plants most resistant to the conditions of industrial air and soil pollution prevailing in a given area. Of equal importance is the study of methods for increasing the resistance of plants to gases.

Although the first investigations of gas resistance of plants were undertaken long ago both in our country (1900-10) and abroad (1860-70), there is still much in this area which remains unclear. The physiological processes in plants under the influence of acid gases are still almost unknown. Nor is there a scientifically based biochemical and physiological theory that would explain the reasons for plant damage caused by gases, or a complete understanding of the different degree of susceptibility of various plant species.

V. Sabashnikov (1911), N. P. Krasinskiy (1937-40), V. Krocker (1950), I. K. Fortunatov (1958), and M. A. Zheleznova-Kaminskaya (1951, 1953) summarized the work of various authors concerning gas resistance of plants. They all consider that acid smoke gases affect photosynthesis, respiration, transpiration, as well as the water regime of plants and also cause acidification of the protoplasm and a change in the ionic balance, which affect the stability of the biocolloids in the plasm.

Many of our investigators (Krasinskiy, 1937, 1940, 1950; Krocker, 1950; Ryabinin, 1962), as well as foreign investigators, established that under the influence of acid gases 1) the cell sap becomes acidified, 2) the intensity of photosynthesis declines, 3) the respiration first drops, and then increases, according to Viller (1905), while, according to Krasinskiy (1950), respiration remains unchanged or increases, 4) the intensity of metabolism is lowered, and the redox potential changes, 5) sulfur and other elements accumulate in the leaves, 6) the amount of ascorbic acid declines, and 7) the drain of assimilators ceases (Viller, 1905).

In severe injuries, the chloroplasts lose their bright color, swell, and even adhere to the cell wall. In damaged cells the chlorophyll changes to pheophytin.

A most general theory of gas injury to plants was advanced by Noack (1920) and developed by N. P. Krasinskiy (1949-50). This theory states that acid gases disturb and arrest the activity of enzymes connected with photosynthesis. Chlorophyll, deprived of its basic function to assimilate carbon dioxide from the air, continues to accumulate photoenergy, acts photodynamically, destroying itself and the substances surrounding it. At the same time there is the formation of phenophytin.

Of great significance to plants is the permeability of protoplasm and its buffer capacity as well as the stability of the plasma biocolloids and of the enzyme complex.

In our study of gas resistance we confined ourselves to investigating photosynthesis and respiration, water conditions, pH, Eh, and rH_2 of cell sap, the movement of stomata, and the quantity of readily oxidizable substances. In addition, we studied the anatomical properties of leaves and the dynamics of their susceptibility to injury in woody plants growing under conditions of the copper smelting industry of the Central Urals (Krasnoural'sk, Kirovgrad, and Revda), as well as in a laboratory gas chamber where cut branches of plants were used.

In the first stage of this work, in 1959-60, the physiological indices were studied for five species: balsam poplar, dwarf apple, European white birch, aspen, and box elder. The investigation was carried out under conditions of intermittent gassing (200 m. from smelter) and under conditions free of gases (trees in a forest glade of about 500 m. diameter and at a distance of 7 km. from the smelter). In the forest glade study the naturally growing aspen and European white birch were utilized. In addition, in the fall of 1959, there were planted balsam poplar, dwarf apple, and European white birch. All analyses were carried out in quadruplicate, three times daily (at 7 A.M., 1 P.M., and 7 P.M.).

According to literature data (Krasinskiy, 1950; Vanifatov, 1959; Bulgakov, 1959, 1961; Ionin, 1961) as well as according to our own observations of the degree of susceptibility of leaves to injury, by the Krasinskiy (1950) method, the trees under study can be grouped as follows: mildly susceptible (box elder); moderately susceptibile (balsam poplar and aspen); and very strongly susceptible (dwarf apple and birch).

The investigations established a relationship between the resistance of woody species to acid gases and the intensity of photosynthesis and respiration. The species having a higher intensity of photosynthesis and respiration are injured to a greater extent by acid gases (dwarf apple and birch).

The extent of daily variations of readily oxidizable substances in the leaves is apparently related to the intensity of physiological processes (photosynthesis, respiration, and others). The variations during the day are insignificant (2-4 ml./1 g. of green weight) for the mildly susceptible box elder, whereas for the strongly susceptible dwarf apple and birch the variations were 8.5-19.5 ml.

It was also found that the gas resistance of the investigated species is correlated to the total water content in the leaves. The leaves of the gas-resistant box elder had a higher water content. The concentration of the cell sap was lowest in the mildly susceptible box elder (9-10%), whereas in the dwarf apple and birch it was one and a half times higher and more.

In this article we shall examine also the effect of sulfur dioxide on the performance of the stomatal apparatus and on some physiological indices: photosynthesis, pH, and the concentrations of cell sap and of oxidizable substances in the leaves. The dynamics of the stomata movement in the course of the day was studied following the penetration of alcohol, benzene, and xylol into the intercellular spaces of leaves. To facilitate the comparison of stomata movement in various species, the following designation was adopted: first degree - implies the penetration of xylol only, (the stomata are practically closed); second degree - refers to the penetration of xylol and benzene, (stomata half open); and third - refers to the penetration of all three (which implies that the stomata are fully open). Taking into account the degree of stomata opening we shall proceed to analyze the stomata movement in leaves of woody plants growing under conditions of intermittent gassing (in a city park) and under conditions free of gas (in a forest) -- see Fig. 1, a and b.

Under environmental conditions free of gas (Fig. 1, b) leaves of naturally growing aspen and birch were studied. In addition, the previous year balsam poplar and European white birch were planted in a forest clearing. Obviously, data on trees transplanted into forest environment cannot be accepted as controls but they will enable us to draw some other conclusions. In the aspen and birch growing naturally in the forest, the average opening of the stomata in June was higher than in the transplanted trees. The dynamics of the stomatal movement in the transplanted trees indirectly confirms the conclusions of A. M. Alekseev (1948) that plants growing in conditions of dry soil reduce the extent of their stomata openings. Weakening of the root system induced by transplantation apparently creates conditions resembling those characteristic of dry soils. The stomata of the naturally growing aspen and birch showed no substantial difference in movements that could influence the rate of their gas metabolism. In all the species growing under forest conditions noticeably enlarged stomatal openings were observed in the fall.

Under conditions of intermittent gassing (Fig. 1, a) the average opening of the stomata of the poplar, aspen and dwarf apple was larger than in the box elder and birch. Considerable reduction in the stomatal movement of the birch may be attributed to a deterioration of the tree caused by the gas - a condition that could also be determined from the appearance of the tree's crown.

Observations of the performance of the stomatal apparatus of the woody species during the summer (Fig. 1, a) show that toward the end of the growing season there was even a greater reduction in the stomatal movement of the box elder - a species of low susceptibility to gas injury. The degree of stomatal opening of the European white birch also decreased, but this was apparently due to the considerable gas injury sustained by the tree. The regulatory apparatus of the stomatal movement of trees exposed to intermittent gassing (Fig. 1, a) reacts differently in different species while under conditions free of gas (Fig. 1, b), the stomata openings enlarge in the autumn, as was to be expected from literature data (Alekseev, 1948).

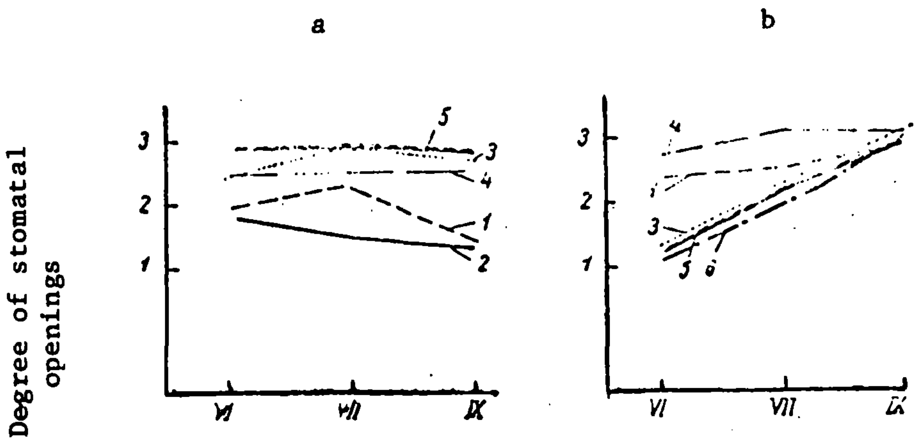

Fig. 1 Change in the average stomata openings during the growing season by month (monthly averages based on 5-7 days' observations).

a - city park; b - forest

1 - European white birch; 2 - box elder; 3 - dwarf apple; 4 - aspen; 5 - balsam poplar; 6 - European white birch, transplanted into the forest glade.

The difference in the movement of the stomata of the trees (Fig. 1, a and b) we are inclined to attribute to the intermittent action of acid gases. This is particularly noticeable in the birch. The greater opening of the birch stomata in July is related to a change of its foliage, which resulted from gas burns. The opening of the stomata of the new foliage on the birch as yet not affected by gassing is the same as in the control plants. It is quite likely that the data for the poplar in autumn (Fig. 1, a) are somewhat higher because the poplar and the aspen had changed their foliage.

It should also be taken into account that conditions of microclimate and soil in the city and in the forest are not identical. According to L. B. Lunts (1952), the city microclimate is characterized by a greater daily amplitude of air temperature variations, a higher air and soil temperature (4-16°C, depending on the soil cover), and a lower relative air humidity. According to our data (Nikolaevskiy, in press) the relative air humidity in the city is lower than in the forest, in July by 14.5% and in September by 6.6%.

According to the data of I. N. Rakhteenko and L. A. Krot (1960) the soil moisture in cities is lower because of a greater surface runoff caused by excessive compaction, by asphalt, concrete, and cobblestone paving. Consequently, the dynamics of stomata motion could be affected by the less favorable climatic and soil conditions in the city as well as by gas.

A study of the stomata movement in the course of summer helps in determining certain causes of leaf injury to the experimental species. Ivanov (1936) and Krocker (1950) suggested a possible connection between the movement of the stomata and the susceptibility of leaves to injury of the various species. Our investigations (Nikolaevskiy, in press) confirm this view.

The severity of leaf injury must then depend on the quantity of acid gas absorbed per unit of dry weight of leaves. The rate of gas absorption depends on the quantity and size of the stomata openings per unit surface of leaf as well as on the presence of intercellular spaces. According to the Stefan Law, a decrease in the stomata openings by half practically does not affect the rate of gas exchange between atmospheric air and the intercellular spaces (Maksimov, 1958).

A further decrease in the stomata openings will result in a smaller but not proportional gas exchange. Therefore, a daily variation in the openings from 3 to 2 (as previously explained) cannot be considered significant for the rate of gas exchange. A lowering of the openings from 2 to 1, or even lower, will affect the gas exchange. Therefore, we cannot discern differences in the rate of gas exchange in the poplar, aspen and dwarf apple during the summer (Fig. 1, a) but there is a discernible lowering of it in the box elder when compared with the others. It can be assumed that a lowering in the rate of gas exchange in the box elder under conditions of periodic gassing contributes to a decrease in the intake of noxious gases, thereby preventing graver leaf injury.

In addition to these field investigations, we set up in March experiments to study the effect of sulfur dioxide on tree leaves. First, the leaves were forced out in a hothouse. Branches were then placed in flasks containing tap water. The leaves of various species were then fumigated in a plexiglas gas chamber, with different concentrations of sulfur dioxide and for different periods of time. Analyses were made the day following fumigation.

We studied the effect of sulfur dioxide on the movement of stomata by the infiltration method, pH changes of leaf sap potentiometrically, photosynthesis by the method of L. A. Ivanov and L. N. Kossovich (1946), the quantity of readily oxidizable substances in the leaves by the N. P. Krasinskiy method (1950), and the concentration of dry matter in the cell sap refractometrically. The results are given in Table 1.

The results show that under the influence of SO_2, the stomata after fumigation were less open than in control plants, even one day later. A mere 10 minutes' exposure to an SO_2 concentration of 1/8000 by volume (experiment No. 1) caused a decrease in the extent of stomata openings.

Table 1

Effect of SO_2 on leaves of woody plants based on the results of investigations in a gas chamber.

Species	Degree of stomata openings		Visible photo-synthesis, mg. CO_2 per 1 dm./hr.		Concentration of cell sap, %		pH of cell sap		Oxidizable matter per 1 g. of raw wt. of leaves		Damage to leaf surface, %
	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	
Exp.#1	Concentration of SO_2 - 1/8000, duration 10 min., illumination 15,000 lux										
Hairy lilac	2	3	+0.5	+1.6	12.0	12.0	5.9	6.4	20.1	17.4	-
Balsam poplar	1	2	-1.3	+0.7	13.0	13.5	6.3	6.5	19.5	30.7	-
Dwarf apple	2	3	-4.0	+2.3	11.0	14.0	6.1	6.3	17.1	28.0	-
European white birch	1	2	-9.2	+21.2	13.5	14.5	6.2	6.5	23.5	28.4	-
Exp.#2	Concentration of SO_2 - 1/4000, duration 20 min., illumination 8,000 lux										
Balsam poplar	2	3	+0.9	+3.5	-	-	-	-	-	-	-
Dwarf apple	2	3	-1.9	+0.8	-	-	-	-	-	-	10
European white birch	0	2	-9.2	+3.3	-	-	-	-	-	-	80
Exp.#3	Concentration of SO_2 - 1/4000, duration 1 hr., illumination 10,000 lux										
Balsam poplar	2	3	-1.2	+3.6	-	-	5.4	6.1	-	-	50
Dwarf apple	1.5	3	-4.2	+2.5	-	-	5.5	6.1	-	-	40
European white birch	2	2	-11.0	+1.9	-	-	5.7	6.3	-	-	100
Exp.#4	Concentration of SO_2 - 1/4000, duration 1 hr., illumination 32,000 lux										
Balsam poplar	2	3	-1.6	+0.3	-	-	5.6	7.2	-	-	100
Dwarf apple	2	3	-1.4	+1.2	-	-	5.8	6.6	-	-	100
European white birch	1.5	2	-5.6	+0.4	-	-	5.8	6.4	-	-	100

Data in Table 1 confirm our conclusion concerning the effect of intermittent gassing on the dynamics of stomatal movement in woody plants during the summer. In all cases where the leaf injury exceeded 5% of the surface area, photosynthesis was arrested, and the respiration during light exposure increased. SO_2 provoked particularly strong respiration in birch and dwarf apple.

Sulfur dioxide caused acidification of the cell sap; it was weak when the fumigation was brief and the SO_2 concentration low (experiment No. 1) and stronger in extended fumigation and higher SO_2 concentration (experiments No. 3 and 4). Simultaneously, there was a decrease in the readily oxidizable substances in the leaves. An exception was lilac in experiment No. 1. In this instance the photosynthesis did not drop and the amount of oxidizable substances increased.

Lowering of the amount of oxidizable substances in the leaves of damaged plants was apparently caused by an increased respiratory intensity. It should be noted that in the experimental plants respiration greatly varied in time. Because of this, data obtained by us for a decrease in oxidizable substances in the leaves of experimental plants show no good correlation with transpiration.

Data of foreign investigators show that sulfur dioxide in concentrations of 0.0000002-0.000001 by volume is capable of lowering the intensity of photosynthesis, however, after fumigation, photosynthesis is restored. Concentrations of 0.000007 or higher, and with the duration of fumigation for approximately 1 hour, bring about considerable injury to the plant (alfalfa) - an injury that is expressed in a substantial reduction of photosynthesis throughout the greater part of daylight during a period of 8-9 days.

Our experiments were conducted at concentrations of 100-200 times that used by the American investigators. This is the reason why we were able to observe complete cessation of photosynthesis, even on the second day after fumigation, and considerable respiration in daylight. As seen in Table 1, following fumigation there is a decrease in the concentration of cell sap in the leaves.

Of equal interest are the data obtained in the study of the effect of SO_2 on leaves of branches cut from woody plants and treated in a gas chamber in summer. The experiment was carried out for 30 minutes on July 17, 1960, at a SO_2 concentration of 1/4000, under 25-30 thousand lux illumination. Unlike the winter experiments, the analyses of the leaves were made the same day, 4 hours after fumigation. (Table 2).

As in the previous experiments (Table 1), here too can be pointed out that under the influence of SO_2 (Table 2) the stomata openings decreased, the pH of the cell sap was lowered, and the quantity of oxidizable substances declined. The concentration of cell sap in the leaves 4 hours after fumigation increased. It can be assumed that under the influence of SO_2 there is during the first few hours an increase in the concentration of cell sap due to sudden hydrolysis, and that on the following days there is a lowering in the concentration resulting from transpiration and absence of photosynthesis.

Table 2

Effect of sulfur dioxide on leaves of woody plants.

Species	Changes of some indices under the influence of SO_2							
	Stomata openings		Concentration of cell sap		pH of cell sap		Oxidizable matter per 1 g. of raw wt. of leaves	
	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control
Poplar	3.0	3.0	-	15.6	5.08	6.20	24.8	27.0
Birch	2.0	2.5	16.0	15.2	4.52	6.08	36.0	45.0
Apple	1.0	2.0	20.8	18.8	5.40	6.22	44.0	46.5
Elm	1.0	2.0	20.0	19.2	5.72	6.02	22.6	26.0
Ash	3.0	3.0	17.6	15.0	5.98	6.05	25.6	28.0
Aspen	2.0	2.0	24.0	21.0	5.62	5.92	23.4	26.3
Box elder	1.0	1.0	-	14.5	4.0	4.05	25.0	25.2

Our anatomical studies showed that under city conditions the intermittent gassing and perhaps also the poorer microclimatic and soil conditions, bring about an increase of xerophilization of the leaves. This is expressed in a decrease in the size of leaves, an increase in the number of stomata per 1 $mm.^2$, a decrease of their size, a decrease in the thickness of the cancellous parenchyma, an increase in the thickness of the epidermis, and also, in the case of strongly susceptible species (dwarf apple and birch), the loss of one layer of palisade tissue.

Phenological observation of the development and drop of leaves of woody plants reveals that under city conditions, and particularly under the influence of gas, the growing period is shortened. In the case of the box elder which is more gas-resistant, the leaves drop later than those of the less resistant species -- the dwarf apple and the birch.

Conclusions

1. Under the influence of acid gases, and particularly under simultaneously acting urban conditions, the five investigated species: box elder, balsam poplar, aspen, European white birch, and dwarf apple, showed a distinct reduction in the openings of their stomata in autumn; the extent of this reduction differed for the different species. In the absence of gassing, the reverse was true.

2. The smallest opening of the stomata during the vegetative period was observed in the box elder. This could be the reason for the decrease in the rate of gas exchange, which is conducive to a reduction in the vulnerability of the leaves to noxious gases.

3. High concentration of sulfur dioxide causes considerable narrowing of the stomata of the leaves of woody species and upsets the normal course of physiological processes. Thus, the intensity of photosynthesis drops and respiration is observed in daylight. In addition, acidification of cell sap and a decrease in the quantity of oxidizable matter is also observed.

4. The greater damages, which manifest themselves in appreciable acidification of the cell protoplasm and in an extensive disturbance of photosynthesis, are observed in the less resistant species - dwarf apple and birch. These disturbances appear to a lesser extent in the more resistant species - poplar and lilac.

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CHARACTERISTICS OF PHOTOSYNTHESIS AND OF SOME OTHER PROCESSES IN CONNECTION WITH SMOKE AND GAS RESISTANCE OF TREES AND SHRUBS

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In the conditions of the Karaganda region, where drought and dry winds are frequent, the establishment of green plantings is of exceptional importance.

However, along with the local adverse conditions of soil and climate, there is also the air pollution factor hampering green plantings in the industrial cities and in industrial areas as a result of the gas, smoke and dust prevailing there. The effect of gas, smoke, and dust on growth, on development, and on the physiological processes of plants has been insufficiently studied. Investigations as to carbohydrate exchange, photosynthesis, and other physiological processes are very limited as yet.

Our objective was to study the processes of growth and plant development, photosynthesis, and the dynamics of carbohydrate and chlorophyll accumulation, under various conditions of growing and of gas pollution. For three years (1959-1961) we investigated the following plants: European white birch, pinnate elm, common lilac, Tartarian honeysuckle, box elder, balsam poplar, oleaster, Scotch pine, and Siberian pea shrub. The plants under investigation were 3-5 years old.

The plants were studied in a number of locations subject to different growth conditions, which can be characterized as follows:

Central Ore Concentration Mill. Five stacks located 200 m. from the plantings discharge continuously smoke and soot. The concentration of CO is 30.0-117.6 mg./m.^{3} and of SO_2, 0.28-1.33 mg./m.^{3}. The air is dust-laden and on certain days the dust concentration is 4.7 g./m.^{3}. The industrial site slopes toward the plantings, which are not protected by buildings from gas and smoke. The soil of the area is dark chestnut, overlaying a mottled, gley, saline clay.

Karaganda Metallurgical Plant. Plantings in the vicinity of the factory are located 300 m. from the blast furnaces and are constantly exposed to gases and to smoke. The soil of the site is dark chestnut, of the solonchak type, modified and polluted by construction rubble.

Karaganda Botanical Garden. Plantings in the Garden are at a distance of 2 km. from a coal cut. In this area there is considerable gas in the air -- CO, up to 117 mg./m.^{3} and SO_2, up to 0.25 mg./m.^{3} on some days; quite frequently, the concentration of these pollutants is insignificant. The area of the Garden is level, and the plants are not shielded from smoke and gases. The dust content of the air is negligible. The soil is dark chestnut, heavy loam over calcareous clay.

During the growing period, observations were made on growth and development of the plants, dynamics of chlorophyll and carbohydrate accumulation, intensity of photosynthesis, and oxidizability of cell sap. Carbohydrate analysis was done by the Bertrand method. Three fractions were determined -- monosaccharides, disaccharides, and polysaccharides. Chlorophyll was determined colorimetrically, in an alcohol extract. Intensity of photosynthesis was determined by the S. V. Tageeva method. Leaves for analyses were taken from the middle layer of the crown on the southwestern side. During the summer, the observations were made in five periods at intervals of 15 to 20 days, exactly at 9 and 11 A.M. and at 1 and 3 P.M. Oxidizability of the cell sap was determined by the N. P. Krasinskiy method. As a result of this investigation the following was found:

1. The development of plants was affected by conditions under which they grew. In the proximity of the Ore Concentration Mill and the Metallurgical Plant, the growth-development phases of box elder, oleaster and Siberian pea shrub were accelerated.

2. Gas and dust pollution near the Concentration Mill and the Metallurgical Plant intensified the growth of lateral shoots in the balsam poplar, oleaster and pinnate elm.

3. In all the plants under study the chlorophyll declined toward the end of the growing season. In the common lilac, oleaster, and pinnate elm growing near the Concentration Mill or the Metallurgical plant the chlorophyll content rose.

4. The intensity of photosynthesis varied in the studied plants ontogenically and in the course of a day.

The highest indices of photosynthetic intensity for most of the studied plants were recorded during the morning hours. Appreciable gas and smoke pollution hampered photosynthesis. However, the same conditions enhanced photosynthesis in the oleaster and in the pinnate elm. This can be accepted as manifestation of adaptability of these species to existing conditions.

5. From the point of view of oxidizability of cell sap, the studied plants can be ranged in decreasing order of their gas resistance: pinnate elm, oleaster, balsam poplar, box elder, Tartarian honeysuckle, Siberian pea shrub, common lilac, European white birch, and Scotch pine. Of the studied plants the most promising for green plantings on industrial sites in the Karaganda coal basin are: pinnate elm, oleaster, and balsam poplar. Box elder, Tartarian honeysuckle, Siberian pea shrub, and common lilac are of moderate resistance. The European white birch and Scotch pine are low-resistant species.

INDICATORS OF GAS RESISTANCE OF ARBOREAL PLANTS
(According to Investigations Conducted in The City of Krasnoural'sk)

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In our country the first studies on the effect of poisonous gases upon plants are attributed to the beginning of the twentieth century (Nelyubov, 1900-1910; Sabashnikov, 1911). They were interrupted during the period of World War I and the [Russian] Civil War, but were resumed during the years of national industrialization. A great interest in selecting gas-resistant plants is developing at the present time in connection with the great spread of industrial and residential construction specified by the Seven-Year Plan for the growth of the Soviet national economy.

Visual, subjective methods of evaluating the degree of gas resistance in plants are characteristic of the majority of the projects carried on up to the present time. The resistance of plants has been determined by the percentage of damage to the leaf surface (Krasinskiy, 1950) or by the ability of transplanted trees to acclimatize (Bulgakov, 1958-1961). The assortments of gas-resistant plants compiled on the basis of the above method of approach are not universal: there are considerable contradictions among them, and their employment under different geographical and soil-climate conditions often yields negative results.

N. P. Krasinskiy (1937, 1940, 1950) has conducted major studies on gas resistance. Proceeding from the fundamental biochemical law of S. L. Ivanov (1926) and the conclusion drawn by A. V. Blagoveshchenskiy (1950) on the biochemical bases of the evolutionary process in plants, Krasinskiy holds that the gas resistance of plants is connected with the systematic position of a species [This probably means the <u>relative classification</u> of a species within a <u>morphological</u> or <u>taxonomic system</u>--Trans.]. He substantiates this connection with data on the damage to plants by gases and the amount of oxidizable substances in the leaves of 18 families of plants. N. P. Krasinskiy (1950) developed methods for studying the gas resistance of plants.

The essential shortcoming in several previous studies (Ionin, Koltasheva, 1961) is the fact that the gas resistance of plants was studied without taking into account the physiological and biochemical processes that take place in leaves under the effects of gases and without regard for the influence of the external environment upon the condition of the plants and their resistance to gases. The compilation of the assortments of gas-resistant plants on the basis of leaf damage and the conclusions of Krasinskiy (1950) does not resolve the questions of the dependency of gas resistance upon the external environmental conditions and upon the condition and the stage of development of the plants. Therefore, they do not answer the practical needs for increasing the gas resistance of plants by selection, raising, maintenance, fertilization, etc.

A certain exception is presented by the work of V. A. Guseva (1950), which showed the possibility of increasing the gas resistance of plants by using fertilizers, and by the work of M. V. Bulgakov (1961).

Other studies by N. P. Krasinskiy (1950) and V. A. Guseva (1950) on the reducing strength, the content of glutathione and ascorbic acid, and the oxidation-reduction potential of plants --- these being of considerable interest for understanding the gas resistance of plants --- were in the nature of preliminary surveys and did not attain any further development.

The gas resistance of arboreal species, in our opinion, can be found to be dependent upon a great number of factors. Among these factors we can note the following: the special anatomical characteristics of the structure of the leaves and the activity of the stomas, the physiological properties of the cell protoplasm (the buffer capacity of the cell contents, the permeability and viscosity of the protoplasm), the quality and stability of enzymes and proteins, the intensity and biochemical direction of the physiological processes in the leaves, the water regime, etc.

In the first step of our studies in a short three-year period it was, of course, impossible to encompass all the points in one study; therefore, we had to limit ourselves to the study of a few of the physiological processes: photosynthesis, respiration, transpiration, the activity of the stomas, the quantity of easily oxidizable substances, the water holding capacity of the leaves, the pH of the cell contents and the concentration of dry matter in the leaves. We also studied the special anatomical features of the structure of the leaves.

The results of the first year's work led us to a conclusion concerning the gas resistance of arboreal plants as a function of the intensity of photosynthesis and concerning the existence of a certain correlation between the gas resistance and the winterhardiness of plants (Sergeev, 1953 and 1961; Nikolaevskiy, in press).

The intensity of photosynthesis was studied by the method of L. A. Ivanov and N. L. Kossovich (1946); stoma activity was studied by the method of infiltration (alcohol, benzene, xylene); and transpiration was studied by rapidly weighing on torsion weights. The concentration of dry matter was determined by the refractometric method in the juice squeezed out by a hand press from leaves killed by steam. The amount of substances oxidizable by a decinormal solution of potassium permanganate was accounted for by N. P. Krasinskiy's method (1950). The pH of the cell contents was studied with an LP-5 potentiometer. The determination was made by small glass and calomel electrodes in the aqueous squeezings from the leaves (2-3 g. of leaves were crushed into 10 ml. of distilled water).

A few of the methods we used are not distinguished by great accuracy. This applies in particular to the determination of transpiration (Sveshnikova, 1959) and pH. However, even though they do not have a high absolute accuracy, these methods were the only possible ones for us under field conditions, because of their lesser complexity and laboriousness, taking into account the great number of other tasks going on at the same time. Besides, we hoped to obtain at least some comparative data of various plant species growing under identical conditions, without claiming an absolute precision of the data.

All determinations were run three times per day: at 7 A.M., 1 P.M. and 7 P.M. with four repetitions, but transpiration with eight to ten repetitions.

In order to ascertain the effect of meteorological conditions upon the physiological processes, we considered the atmospheric humidity (by an August psychrometer), the daylight exposure (by a luxmeter), and measured air temperature at the top of the tree.

Simultaneously we made use of the data of the meteorological station at the Krasnoural'sk municipal park administration, submitted by M. V. Bulgakov.

The subjects of the study were trees selected in a public garden located 200 m. from the gas sources and, therefore, subject to their effects to a great degree. The trees were 12 to 15 years old. All the studies were conducted during the summer on five arboreal species: aspen [Populus tremula], balsam poplar [Populus balsamifera], box elder [Acer negundo], Siberian crab apple [Pyrus baccata], and European white birch [Betula verrucosa]. The leaves used for testing were taken during the summer from the same trees from their south side in the middle of the crown.

The control trees used were aspens and European white birches of natural origin in the Krasnoural'sk Forest, located 7 km. southeast of the factory. In addition to these, balsam poplar, Siberian crab apple, and white birch were planted in the same place in the autumn of 1959. Therefore, the results observed on these transplanted trees cannot be considered as controls, but they characterize the condition of arboreal species after transplanting.

The control trees were located in a large forest glade and were not subject to any specific effect of forest conditions.

Meteorological Conditions During the Growing Period

The meteorological conditions during the growing period are not very favorable for the normal growth and development of plants. Spring in Krasnoural'sk is usually lingering and cold, which is in general characteristic of the Central Urals. Late spring frosts occur even up to the middle of June. Snow falls on the budding leaves at the end of May or the beginning of June almost every year.

Growth of arboreal species begins almost one week later than in Sverdlovsk, i.e., at the end of the first half of May. Late frosts and snow bring about no less damage to the leaves of the arboreal species than do gases. In two or three days after a snowfall, there appear on the leaves blotches reminiscent in color and form of actual gas burn.

In 1961 during a snowfall on the fifth of June, we were able to conduct a series of experiments on the effects of fallen snow on the leaves of arboreal species. These data allowed us to notice the sharp decrease in the intensity of the physiological processes in leaves as expressed by the decrease in concentration of cell sap and the shifting of pH to the alkaline side. In the arboreal species more resistant to late spring frosts, the decrease of these indices occurs at a lesser degree than in the nonresistant species.

Early autumn frosts in Krasnoural'sk occur in the second half of August, which, just as do acid gases, leads to earlier losses of decorative quality, to the cessation of growth, and to the deterioration in the condition of the urban verdant plantings (Table I).

Table 1

Meteorological data for the 1960 growing period in Krasnoural'sk.

Month	Number of days			Precipitation, mm.	Relative humidity, %	Average temp., °C	Maximum wind speed m./sec.
	Clear	Partly cloudy	With precipitation				
May	2	18	11	30.4	--	6.6	8
June	1	20	9	47.5	72	16.4	10.5
July	2	14	15	42.7	82	16.1	7
August	5	19	6	16.8	76	13.6	5
First half of September	1	8	5	16.0	90	11.6	--
Total	11	79	46	153.4	80	14.2	

The growing period was characterized by relatively low maximum temperatures and sufficient precipitation. But in July and August of certain years, there occur dry periods, and the temperature of air in the soil may reach, according to our observations, 45 to 48°C. (26-27 July 1960).

The number of cloudy and rainy days comprises 34% of the total number of days of the growing period. In the remaining 2/3 of the period, increased sunlight is observed (clear or partly cloudy days), i.e., such weather conditions that are conducive to maximum gas damage when gas pollution occurs; as indicated by L. A. Ivanov and also by V. Kroker (1950).

According to the data of the meteorological station of the Krasnoural'sk Municipal Park Administration, the number of days with gas pollution during 1960 was found to be as follows:

June....................1 day
July....................7 days
August..................6 days
September (1/2 mo.)....1 day

The maximum concentration of harmful gases in the vicinity of the industrial plants in Krasnoural'sk is very high. According to data by L. V. Timofeeva (1958), the concentration of harmful acid gases (SO_2, F) in the vicinity of copper smelting concerns is 8 to 10 times higher than the permissible standards set by sanitary regulations. In addition, the microclimatic conditions for arboreal species deteriorate significantly in the cities and in industrial centers. The air temperature in July-August at the surface of cobblestone pavement is 4 to 16°C higher, and 8 to 23°C higher on asphalt pavement, than at the surface of lawns and the tops of arboreal species (Lunts, 1952).

Taking into account the particularly severe microclimatic conditions for the verdant plantings in the city -- namely, the effect of asphalt surfacing of sidewalks and streets upon the temperature of the air and the great amount of dust and of gas pollution -- it becomes evident that the environmental conditions are extremely unfavorable for the growth of urban plantings. This is also reflected in the gas resistance of arboreal species.

Results of the Studies

It must be taken into account that with some species we could not adhere strictly to the methods we used at the beginning of the work. The deviations lie in the fact that the birch in the public park renewed its leaves at the beginning of July, and the poplar, at the end of July; this was reflected in all the physiological indices. In the birch the changes began from the twentieth of July, and in the poplar, after 2 August. In addition, we could not maintain uniformity of the environmental conditions for the crab apple. Thus, in the middle of the day the crown of the crab apple was shaded by the poplars standing close by, which could have influenced, to a certain degree, the indices obtained and the susceptibility of the leaves of a given tree to gas damage.

Before we proceed to the analysis of the processes studied, it is necessary to evaluate the gas resistance of each of the arboreal species and the change in resistance during the year (Figure 1).

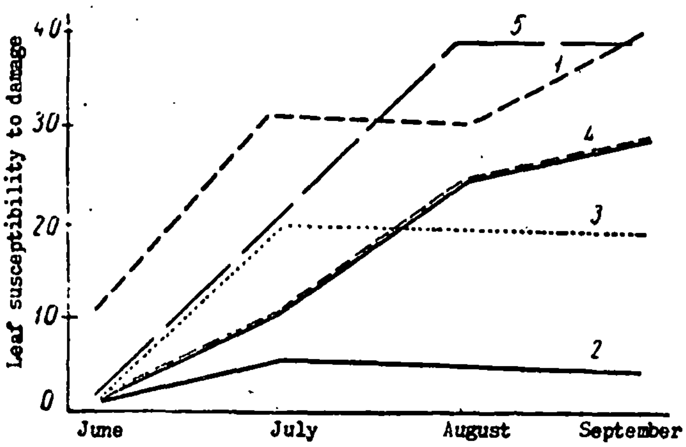

Fig. 1: Change in the susceptibility to damage of leaves during one year in different trees. (1) birch; (2) box elder; (3) crap apple; (4) poplar; (5) aspen; (6) transplanted birch (not shown on graph.--Trans.)

During the summer a regular increase of leaf damage by harmful gases was observed. This is connected with the distribution of days in the month during which there was the effect of gas on the verdant plantings of the city.

In accordance with the scale proposed by N. P. Krasinskiy (1950) and on the basis of the means for the growing period (Table 2), the degree of susceptibility to damage of the arboreal species is classified in the following manner:

Box elder	very low (less than 5%)
Balsam poplar	low to medium (10-20%)
Aspen	medium (20-30%)
White birch	medium-to-high (30-40%)
Siberian crab apple	low-to-medium (10-20%)

In the Siberian crab apple trees growing in open areas, the degree of leaf damage was close to that indicated for the birch. This suggests that the two species have similar low resistance to gases.

The intensity of damage caused by gases depends, when other conditions are equal, upon the concentration of the gases in the atmosphere and the duration of exposure. Therefore, on the basis of data that we obtained on the susceptibility to damage of the leaves of arboreal species as well as on the basis of data found in literature (Krasinskiy, 1950; Vanifatov, 1959; Knyazeva, 1950), it can be briefly summarized that the arboreal species studied have been classified as (a) lightly-damaged (box elder), (b) medium-damaged (poplar, aspen), and (c) heavily-damaged (crab apple, birch).

We shall begin the characterization of the physiological conditions of the arboreal species studied with the description of the way the stomas function. The dynamics of their activity during the day were studied on the basis of the penetration of alcohol, benzene, and xylene into the intercellular channels of the leaf. In order to facilitate comparison, we substituted arbitrarily numerical symbols for the designations of the infiltrating liquids; at the same time, these symbols represent the relative sizes of the stoma apertures. Since xylene (1) can penetrate even into stomata that are almost closed, the number 1 designates the minimum sizes of the stoma apertures. Benzene can penetrate half-open stomata (2) and alcohol penetrates completely open stomas (3).

This method subsequently facilitates the treatment of materials and the comparison of the operation of the leaf stoma apparatus both during a day and during the entire year.

Only xylene can penetrate the intercellular channels of leaves of arboreal species when the stoma apertures are only slightly open (1 and less). The amount of liquids which can penetrate into the intercellular channels of the leaves increases in proportion to the stoma aperture; all three chemical compounds penetrate fully open stomata.

In studying stoma activity, we evaulated the degree of penetration of alcohol, benzene, and xylene into the intercellular channels of a leaf as good, medium, and poor. Poor penetration of benzene simultaneously implies good penetration of xylene.

Table 2: Mean monthly indices of the intensity of physiological processes in the species in the forest and in the public garden.

Species	Actual photosynthesis, mg. CO_2 per dm^2/hr.	Respiration, mg. CO_2 per dm^2/hr.	Transpiration, g. per dm^2/hr.	Water content of the leaves, %	Amount of substances oxidizable by $KMnO_4$ per g. green wt.	Damage caused by gases, %	Actual photosynthesis, mg. CO_2 per dm^2/hr.	Respiration, mg. CO_2 per dm^2/hr.	Transpiration, g. per dm^2/hr.	Water content of the leaves, %	Amount of substances oxidizable by $KMnO_4$ per g. green wt.
Public Park						June					
Box elder	7.2	2.4	1.880	76.7	16.2	0.0	7.5	1.4	1.00	77.4	14.6
Poplar	11.9	5.2	1.060	71.8	20.3	0.0	10.4	1.8	1.14	72.8	19.4
Aspen	8.2	2.8	0.554	64.6	21.3	0.0	7.8	1.2	0.62	64.7	19.6
Birch	13.2	2.4	0.827	68.6	25.0	10.0	10.1	1.7	0.56	66.8	24.4
Crab apple	9.9	2.4	1.510	65.3	36.5	0.0	5.7	1.6	1.44	65.2	34.9
						July					
Box elder	6.6	1.6	1.307	75.0	21.4	5.0	5.7	1.1	1.13	76.6	16.6
Poplar	7.5	2.6	1.280	67.8	29.3	10.0	5.2	1.8	0.72	66.8	28.2
Aspen	9.2	1.9	0.934	56.1	35.9	20.0	6.6	1.7	0.58	56.9	34.4
Birch	15.5	3.4	1.670	74.3	24.8	30.0	12.8	2.2	1.05	74.9	21.8
Crab apple	9.7	1.6	0.890	62.7	46.0	20.0	8.3	1.7	0.74	61.6	44.4
						August					
Box elder			No data			5.0	5.9	0.8	0.532	75.2	26.0
Poplar						25.0	11.2	2.3	1.168	69.3	26.2
Aspen						40.0	8.8	1.3	0.680	56.9	32.0
Birch						30.0	18.1	1.9	1.23	72.9	24.2
Crab apple						20.0	11.2	1.5	0.98	60.2	52.6
						September					
Box elder	4.4	1.6	0.390	73.0	27.3	5.0	5.5	0.7	0.286	73.2	27.8
Poplar	8.1	1.6	0.540	63.4	44.7	30.0	5.1	1.6	0.265	67.2	36.6
Aspen	3.1	1.5	0.462	59.4	43.9	40.0	5.9	1.3	0.254	58.45	40.8
Birch	9.2	1.6	0.450	65.2	51.8	40.0	9.2	1.6	0.545	65.90	48.3
Crab apple	5.9	1.8	0.420	59.4	66.7	20.0	4.2	1.2	0.377	57.75	53.9

Table 2: (Continued)

Species	Actual photosynthesis, mg. CO_2 per dm^2/hr.	Respiration, mg. CO_2 per dm^2/hr.	Transpiration, g. per dm^2/hr.	Water content of the leaves, %	Amount of substances oxidizable by $KMnO_4$ per g. green wt.	Damage caused by gases, %	Actual photosynthesis, mg. CO_2 per dm^2/hr.	Respiration, mg. CO_2 per dm^2/hr.	Transpiration, g. per dm^2/hr.	Water content of the leaves, %	Amount of substances oxidizable by $KMnO_4$ per g. green wt.
					Average data for the growing period						
Box elder	6.1	1.8	1.190	74.8	21.6	4.0	6.2	1.0	0.737	75.5	21.2
Poplar	9.2	2.3	0.960	67.6	30.6	16.5	8.2	2.1	0.822	69.2	28.0
Aspen	6.8	2.3	0.650	60.0	33.8	25.0	7.2	1.4	0.535	59.3	31.3
Birch	12.6	2.7	0.980	66.9	34.0	30.0	12.5	2.2	0.847	69.0	29.3
Crab apple	8.5	2.0	0.940	62.5	49.8	15.0	7.4	1.7	0.886	61.2	47.2
Forest			Clear			June			Cloudy		
Poplar	9.3	3.5	0.75	73.7	18.2	—	10.1	3.5	—	—	19.2
Aspen	9.3	2.6	0.62	71.6	19.4	—	8.9	2.3	—	—	19.0
Native birch	14.7	1.6	0.35	66.5	22.0	—	12.9	4.80	—	—	28.0
Transplanted birch	4.6	2.0	0.467	64.8	22.0	—	—	—	—	—	—
Crab apple	9.0	4.1	0.42	68.9	32.3	—	9.5	4.0	—	—	34.0
						July					
Poplar	10.6	1.5	0.65	72.8	25.5	—	No Data				
Aspen	7.9	1.7	1.41	60.75	30.1	—					
Native birch	12.8	3.1	0.965	66.8	28.6	—					
Transplanted birch	13.0	3.1	0.750	63.6	30.3	—					
Crab apple	8.8	1.6	0.67	65.4	46.8	—					
						September					
Poplar	4.1	1.4	0.39	68.8	31.9	—	6.1	1.2	0.580	69.4	32.0
Aspen	6.1	1.3	0.19	61.9	33.1	—	5.3	1.0	0.378	62.7	32.1
Native birch	19.1	5.5	0.537	65.1	34.9	—	10.8	2.1	0.328	63.5	32.4
Transplanted birch	12.3	1.4	0.254	59.9	30.8	—	11.6	0.9	0.275	65.7	29.5
Crab apple	9.8	1.8	0.39	61.1	62.1	—	5.6	1.2	0.328	60.6	48.4
					Average data for the growing period						
Poplar	8.0	2.3	0.596	71.7	25.0	—	8.1	2.2	0.580	69.4	25.6
Aspen	7.8	1.8	0.760	64.7	27.6	—	7.1	1.6	0.378	22.7	25.6
Native birch	15.5	3.4	0.617	66.2	28.5	—	11.9	3.3	0.328	63.5	30.2
Transplanted birch	9.9	2.1	0.490	62.8	27.6	—	11.6	0.9	0.275	65.7	29.5
Crab apple	9.2	2.5	0.492	65.1	47.2	—	7.5	2.4	0.328	60.6	41.2

Hence, the degree of stoma aperture is represented by the following arbitrary symbols:

	Xylene	Benzene	Alcohol
Poor penetration	0.0	1.0	2.0
Medium penetration	0.5	1.5	2.5
Good penetration	1.0	2.0	3.0

We shall analyze the activity of the stomata in the leaves of the arboreal species under conditions of periodic emmissions of gases (Figure 2a) and without them (Figure 2b). The mean monthly data are derived from 5- to 7-day observations.

It is evident from Figure 2 that the average dimensions of stoma aperture in the poplar, crab apple, and aspen in the public park are greater than in the box elder. The degree of stoma aperture in the birch is less than half of the maximum possible dimensions. This means that there is a considerable regulation of stoma movements and this is explained as being the result of the deterioration during recent years of the tree's condition under the effect of gases. The deterioration can be seen even from the external appearance of the crown.

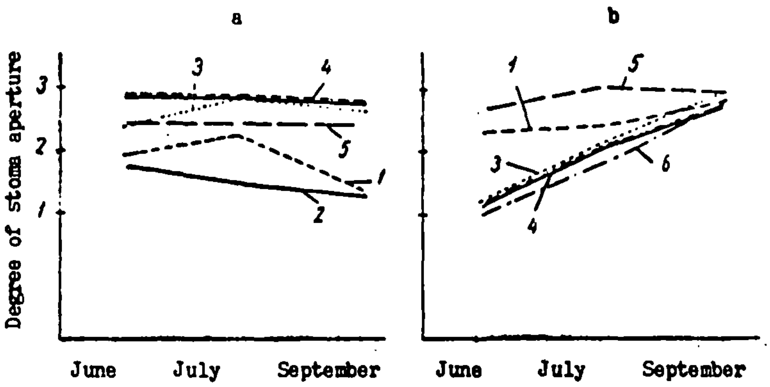

Fig. 2: Change in the degree of average stoma aperture during the growing period.
(a) Public park; (b) forest (arbitrary numbers are the same as in Figure 1).

In the aspen and birch growing naturally in the forest, the daily average degree of stoma aperture is greater than that of the trees in the public park. The average stoma aperture dimensions for the entire growing period are smaller in the crab apple and poplar trees transplanted to the forest in 1959 than they are in the trees in the public park. In the transplanted birch, however, the stoma aperture in the forest and in the park are of similar dimensions. This can be explained (1) by the effect of transplanting upon stoma activity in the trees transplanted to the forest and (2) by the deterioration of the condition of the tree in the case of the birch in the public park.

In the public park the regulation of stoma activity is most noticeable in the box elder and the birch while in the forest it is most noticeable in the transplanted poplar, crab apple, and birch trees.

Increases in the degree of stoma aperture in the birch exposed to the effect of gases can be observed in July (Figure 2). This is explained by the replacement of its leaves. If there were no replacement of the leaves, the curve indicating the change in the degree of stoma aperture in the birch evidently would be parallel on the graph to the one for the box elder. The same behavior of the stoma apparatus in the arboreal species differing in their susceptibility to injury can be explained by the fact that the decreasing sizes of stoma aperture in the box elder is probably a characteristic of the species, and in the birch, it is the result of considerable damage caused by the poisonous gases and by the continuous yearly deterioration of the tree. This is also substantiated by the performance of the stoma of the birch trees not exposed to gas emissions during the summer.

The study of stoma activity during the summer is conducive to some clarification of the reasons for the different susceptibility to leaf damage of the studied species. In a number of papers (Ivanov, 1936; Wislicenius, 1914; Jahnel, 1954) there are references to a possible connection between stoma activity and the degree of susceptibility to leaf damage in different species.

The intensity of the damage to leaves by gases must depend upon the amount of absorbed acid gas per unit of dry or green weight of the leaves; whereas the rate of gas absorption depends upon the number and sizes of stoma apertures per unit of leaf surface and upon the presence of the intercellular channels. The reduction of stoma aperture by one-half, according to Stefan's law for stomata, affects hardly, if at all, the rate of gas exchange between the air and the intercellular channels of the leaf (Maximov, 1958). Further narrowing of stoma apertures causes a regular but nonproportional reduction in the gas exchange rate. This means that with the variation of size in the stoma apertures during the day within a range of from 3 to 2 (in our arbitrary symbols) we cannot speak of differences in the gas exchange rate. The reduction of the stoma apertures from 2 to 1 and less will cause decreases in the rate of gas exchange.

Considering the foregoing statements, we cannot speak of essential differences in the gas exchange rate in the poplar, aspen, and crab apple during the summer, but in the case of box elder one can observe a substantial decrease in its gas exchange rate when comparing it with that of the other trees (see Figure 2). It can be assumed that the reduction of the gas exchange rate in the box elder under the effect of gases is conducive to a decrease in absorption of the harmful gases and to an increase in its resistance.

In the young birch leaves subject to periodic exposure to gas emissions, the average size of the stoma apertures is half of their possible size (July-2, Figure 2a). This, according to Stefan's law, does not restrict the rate of gas exchange, is conducive to a significant absorption of sulfur dioxide and leads to considerable leaf damage. During the fall in these same birch leaves, a substantial decrease in the stoma apertures is observed when compared either to the summer stoma apertures data or to the stoma data of the birch not exposed to gas emissions. The decrease in the gas exchange rate during the fall observed in the birch under exposure to gas emissions (see Figure 1a) is explained by the effect of the considerable gas damage to the leaves.

A comparison of the function of the stoma apparatus in the leaves (Figure 2a, 2b) shows that, at the end of the growing period a decrease in the average size of stoma aperture is observed in all species in the public park, while in the forest the reverse is true because the stoma aperture increases. An exception is the July data for the birch and poplar. An especially sharp increase in the degree of stoma aperture is observed towards fall in the arboreal species transplanted to the forest. Such difference in the behavior of the stoma apparatus between the leaves of the arboreal species in the public park and in the forest evidently developed as a result of the effect of the poisonous gases in the former and the absence of gases in the latter case.

The intensity of the basic physiological processes (photosynthesis, respiration) is, to a significant degree, connected with the functioning of the stoma apparatus. The monthly indices of the intensity of actual photosynthesis are based on averages derived from 3- to 4-day observations.

It can be seen from Figure 3 and Table 2 that the greatest intensity of photosynthesis in the public park takes place during clear weather in the birch, poplar, and crab apple, and the least intensity is found in the box elder. If we consider the intensity of photosynthesis in July (when we observed the greatest number of days with the presence of gas and one could have expected the presence or absence of the connection between photosynthesis and the susceptibility to leaf damage due to gases) then it is clear that according to their intensity of photosynthesis the species can be classified from highest to lowest as follows: birch, crab apple, aspen, poplar, and box elder. It can be seen from Table 2 that all the species, except the crab apple, have the same sequence of susceptibility to gas damage in July.

Consequently, the species characterized by a higher intensity of photosynthesis are damaged to a greater degree by gases. This substantiates our preliminary conclusion concerning the dependency between the intensity of photosynthesis and gas resistance.

In cloudy weather (Figure 3c), because of the different light requirements of arboreal species, there is no such close connection, but it is evident here as well that in July the highest intensity of photosynthesis is observed in birch and crab apple while the lowest is observed in poplar and box elder.

It can be seen from Figure 3b that birch and crab apple in the forest hold first place in their intensity of photosynthesis. Consequently, the indices of yearly average intensity of the photosynthesis of the trees growing in the public park and in the forest are quite similar. The photosynthesis indices obtained for birch in the forest were high because of the younger calendar age of the leaves.

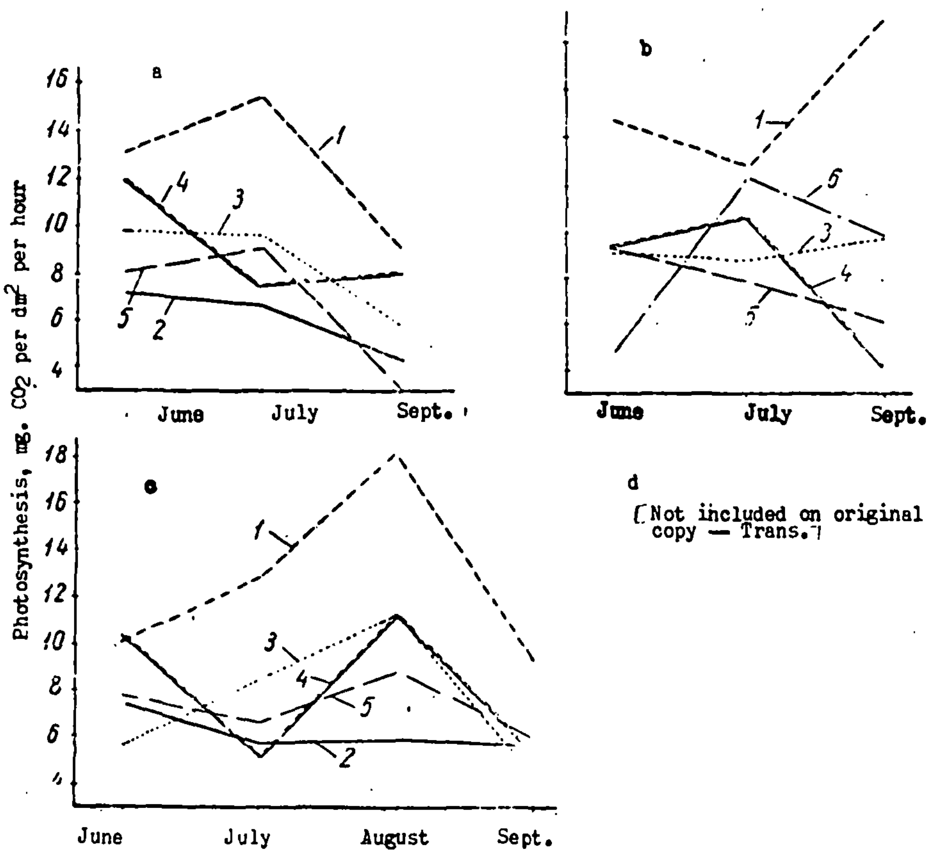

Fig. 3: Change in the intensity of photosynthesis during summer.

(a) Public park, clear; (b) forest, clear; (c) public park, cloudy; (d) forest, cloudy [Graph missing — trans.]. (Arbitrary symbols are the same as in Figure 1.)

Some scientists (Ivanov, 1936; Kroker, 1950; Wislicenius, 1914) assume that the degree of the damage in plant leaves caused by acid gases is dependent upon the intensity of photosynthesis. They note that under conditions that are conducive to the increase in the intensity of photosynthesis, the plants are more damaged by acid gases. The authors point out that a preliminary storage of plants in the dark for two or three hours before exposure to gas emissions contributes to the reduction of susceptibility to leaf damage because of gases.

Wieler (1905) indicated a greater susceptibility to injury in the case of the coniferous needles of a two-year-old pine than of those of a one-year-old pine. The reason for this effect he considered to be the increased intensity of photosynthesis. This is confirmed by the data of A. V. Savina (1941), whose data indicate that the intensity of photosynthesis in the needles of a two-year-old pine is 1.5 to 2.5 times higher than that of the one-year-old pine.

According to current concepts (Kretovich, 1961; Kolesnikov, 1959), biochemical processes of plants during photosynthesis and during respiration are closely interrelated. Therefore, the study of respiration in the arboreal species concurrently with the study of photosynthesis is of considerable interest.

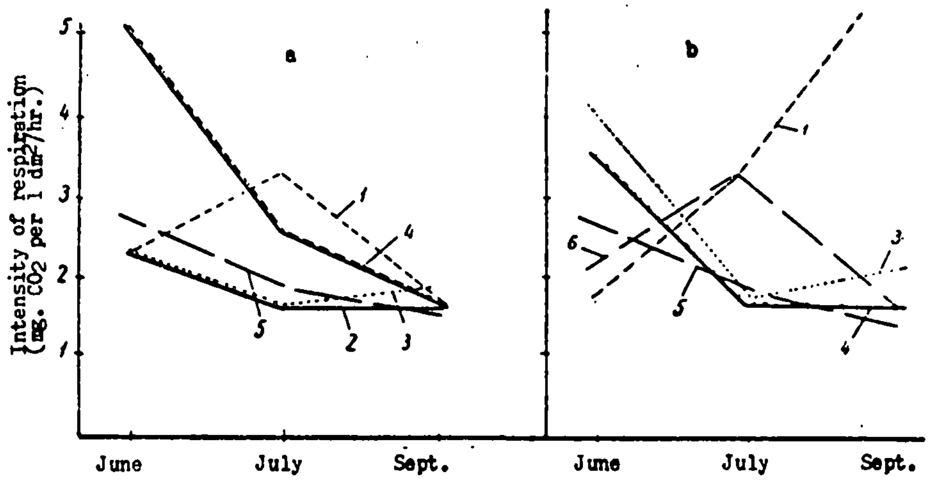

Fig. 4: Change in intensity of respiration during the summer.

(a) Public park; (b) forest

(The arbitrary symbols are the same as in Fig. 1.)

The data on intensity of respiration shown in Figure 4a and 4b indicate that with arboreal species we find the same interdependence between respiration and gas resistance as obtains between photosynthesis and gas resistance. During clear weather the average intensity of respiration for the growing period of all arboreal species studied, with the exception of crab apple, is analogous in sequence to that for photosynthesis. This can be seen from the following figures: box elder 1.8 mg., poplar and aspen 2.3 mg., birch 2.7 mg., and crab apple 2.0 mg. per dm^2 per hour. The arboreal species have also the same sequence for susceptibility to gas leaf damage.

It has been observed that the minimal intensity of respiration for all arboreal species is during the middle of the summer. Towards the fall the intensity of respiration continues to decline or increases slightly. The data shows that birch growing in the forest (natural and transplanted, Figure 4b) as well as in the public park constitutes an exception, seemingly because of the differences in the calendar age of the leaves.

Respiration, of course, goes on during photosynthesis and its relative share of participation in actual photosynthesis, expressed in percentage has been found to equal 29.5% for the only slightly susceptible to gas damage box elder and 21 to 23% for the greatly susceptible to gas damage species of birch and crab apple.

The position developed by several investigators (Ivanov, 1946; Blagoveshchenskiy, 1950) concerning the relationship of the physiological and biochemical processes as well as their intensities to the systematic classification of plant species makes it possible to understand the interdependence between intensity of photosynthesis and of respiration, and of gas resistance of plants. Actually, if the magnitude of gas damage depends upon the extent and intensity of photo-oxidizing processes in the leaves when photosynthesis is stopped by the effect of acid gases (Noack, 1920; Krasinskiy, 1950; Jahnel, 1954), then the intensity of photo-oxidation must depend upon the photosynthetic and the enzymatic activity of the protoplasmic structures, which we are able to judge to a certain degree by the intensity of photosynthesis and respiration.

Consequently, on the basis of the indices of photosynthesis and leaf respiration in arboreal species, even without exposure to gas emissions, we can assume possible injury to the leaves of arboreal plants in the case of periodic effects of gas emissions.

Thus, the arboreal species that are only slightly susceptible to damage by acid gases (box elder) are characterized by a low intensity, and those greatly susceptible (birch, crab apple), by a high intensity of photosynthesis and respiration during their growing period.

As shown by L. A. Sergeev (1961), the species having a reduced intensity of photosynthesis and respiration are more winterhardy. Here, in our opinion, is indicated some analogy between hardiness of plants and their resistance to acid gases.

The results of studies of transpiration in arboreal species suggest that transpiration is the least reliable or stable index. The instability of transpiration is explained (Sveshnikova, 1959) by its essential dependency upon the meteorological conditions. In the poplar, birch and crab apple growing in the public park, the data obtained in clear weather are close to the average per year intensity of transpiration, and the highest intensity of transpiration was found in the box elder (Figure 5a and Table 2). During cloudy weather, the intensity of transpiration decreases in all species. In the three species mentioned above, the indices of transpiration are rather close (Figure 5c). In the case of box elder, when compared with other species in the public park, a more significant decrease of the transpirational water consumption was found during the cloudy weather.

The intensity of transpiration of trees in the forest (Figure 5b) is smaller in comparison with the same species in the public park, the only exception being aspen. The decreasing intensity of transpiration in the transplanted species in the forest is the result of the transplantation.

The determination of leaf water content was made by drying the leaves to a constant weight at temperatures of 100 to 102°C. Leaves that were taken during the summer for the study of transpiration were utilized for the water content determination.

It can be seen from Figure 6a that the crab apple and the aspen have lower leaf water contents during the summer than do the other species, while the box elder leaves have the highest water content. In the case of birch in the public park, the increase of the total moisture in July can be explained by a change of its leaves [renewal of leaves: translator's note]. If the change of leaves is not to be considered, then the average leaf water content in the birch is lower than in the poplar, and this is also verified by the change of the leaf water content in the natural birch in the forest.

Consequently, the box elder, which is only slightly susceptible to damage by gases, is characterized by an increased total water content of its leaves.

In the natural birch growing in the forest, the leaf water content is close to that of the birch planted in the public park; in the aspen, the leaf water content is higher. In trees newly planted in the forest, with the exception of birch, the leaf water content is higher than in the public park trees. This fact is explained by the effects of transplantation (Figure 6b).

With all arboreal species the total water content in the leaves decreases as autumn approaches, but in the box elder this decrease is less pronounced than in other species.

The susceptibility of the leaves to damage by gases in the species studied is well correlated with the total water content of the leaves. The box elder, which is resistant to the gases, is characterized by a high water content, while the medium and the highly susceptible to gas damage species (poplar, aspen, birch, and crab apple), are characterized by a low leaf water content.

Concurrently with the study of photosynthesis, respiration, and transpiration that take place during the day determinations were also made of the amount of oxidizable substances in the leaves (Figure 7). The quantitative study of the easily oxidizable substances in the leaves was made in order to verify some of N. P. Krasinskiy's (1950) conclusions and also in order to study the relationship between the daily course of photosynthesis and the quantitative change of oxidizable substances in the leaves. To make sure that the changes in the leaf water content during the day do not alter the indices calculated per kg. of the green weight, the leaves from the public park were taken in distilled water to a chemical laboratory at the factory. Prior to taking samples for weighing and pulverization, leaves were carefully squeezed out between sheets of filter paper.

The quantity of oxidizable substances in the plant leaves (as shown in Figure 7a, 7b, and 7c) characterizes the resistance of plants to gases. In the box elder, which is only slightly susceptible to damage by gases, the amount of oxidizable substances is 1.5 to 2 times lower than in the birch and the crab apple. During summer, the amount of oxidizable substances in the leaves increases, but this increase varies with different species, as can be seen from Figure 7a. Towards autumn the increase of oxidizable substances in the box elder leaves is less intensive than in the poorly resistant species, i.e., in the crab apple and the birch. Their content is lower in the leaves of the forest trees than in the leaves of the trees growing in the public park.

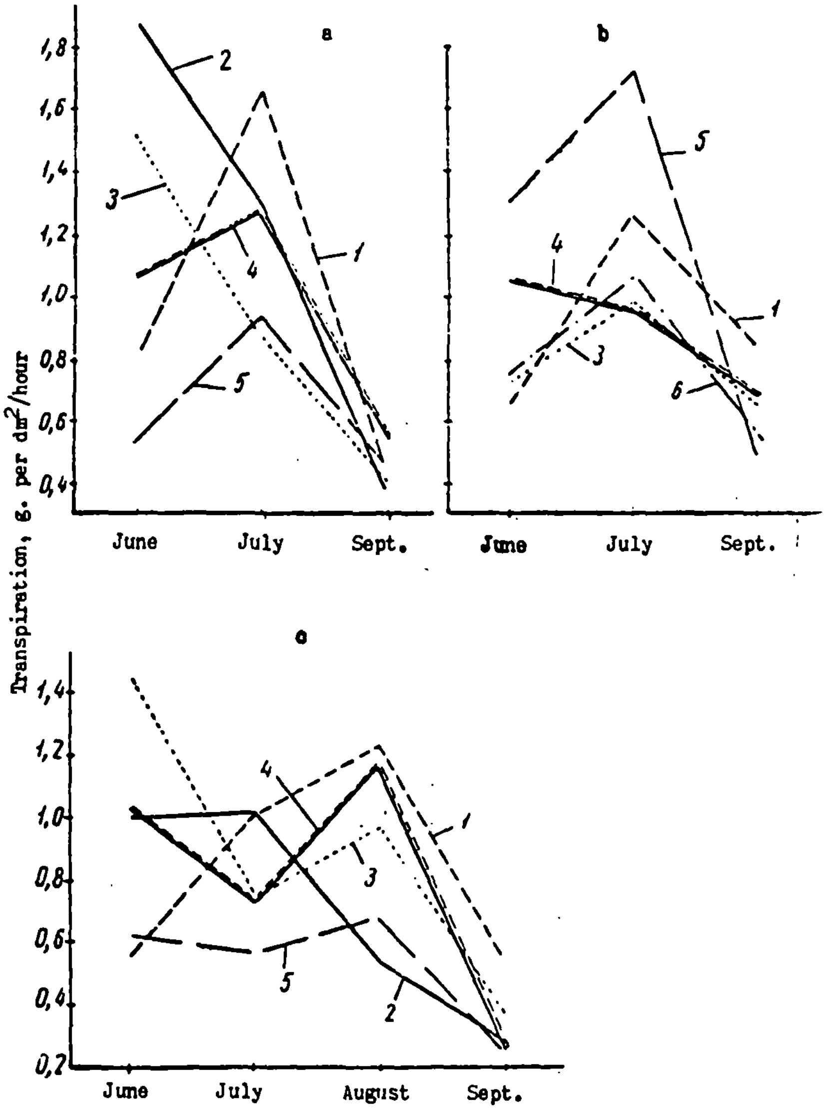

Fig. 5: Transpiration of the arboreal species during summer.
(a) Public park, clear; (b) forest, clear; (c) public park, cloudy.
(Arbitrary numbers are the same as in Figure 1.)

N. P. Krasinskiy's (1950) identification of the quantitative indices of the easily oxidizable substances in the leaves with the character and degrees of photo-oxidations arising in living plant cells under the effects of acid gases has raised serious objections among physiologists.

Of course, the chemical processes of the oxidation of dead plant substrate can not be identified with the biochemical processes in living plant cells because, first, we deal here with a completely different condition of matter and, second, upon the acidification of the substrate to pH 1 or lower, the picture is deliberately distorted; the latter is because of the fact that the amount of oxidizable substances increases as a result of the oxidation of difficultly oxidizable or nonoxidizable substances which are found under normal conditions in plant cells.

Proceeding from the fundamental biochemical law of S. L. Ivanov (1926), we cannot be sure that with a substantial acidification of plant substratum there will develop with different plant species an identical and monotypical increase in the amount of oxidizable substances. The basis of the method for determining the amount of oxidizable substances, as recommended by N. P. Krasinskiy (1950), ignores these important aspects.

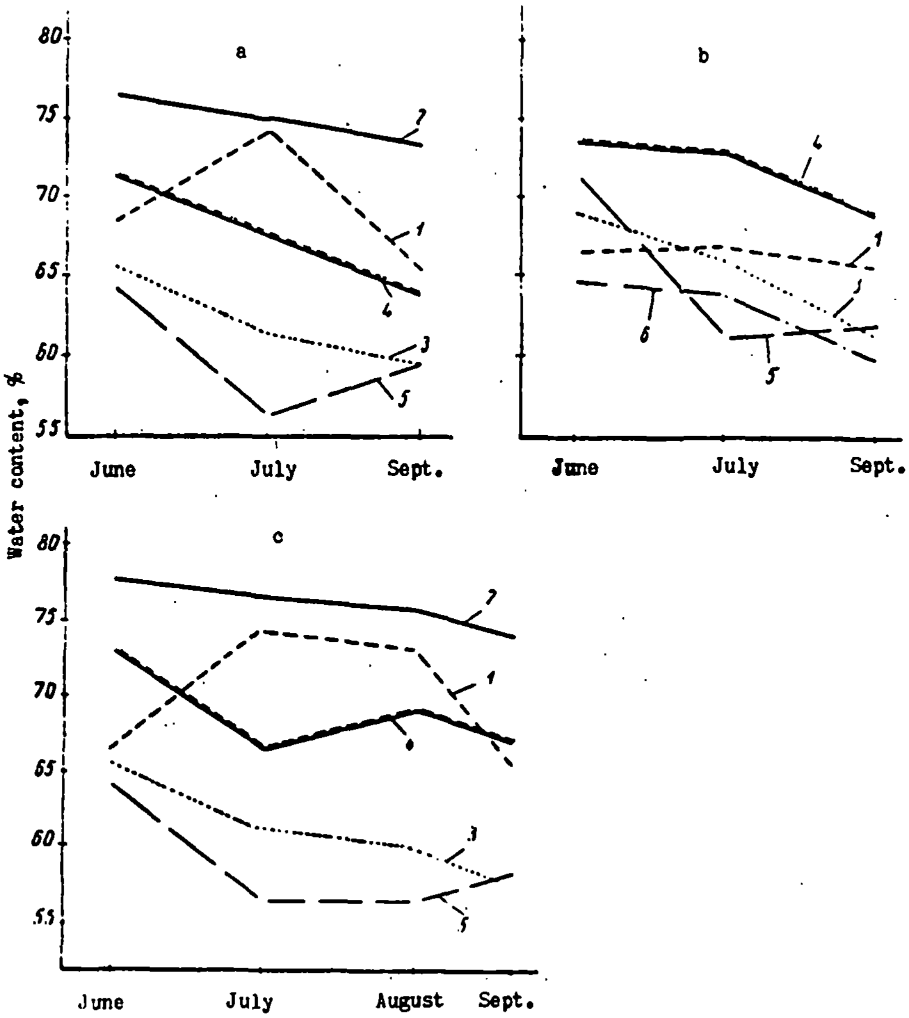

Fig. 6: Change of leaf water content during the summer.
(a) Public park, clear; (b) forest, clear; (c) public park, cloudy.
(The arbitrary numbers are the same as in Figure 1.)

Apparently, he assumed that upon acidification of the cellular substrate, there will be a similar increase in the oxidizable substances in different plant species and, as a result of this similar background of the assumed increase of oxidizable substances, the differences in the content of oxidizable substances in the leaves of the different species will be retained.

In view of the above observations, it appears to be necessary to be cautious in the use of the data obtained by this method.

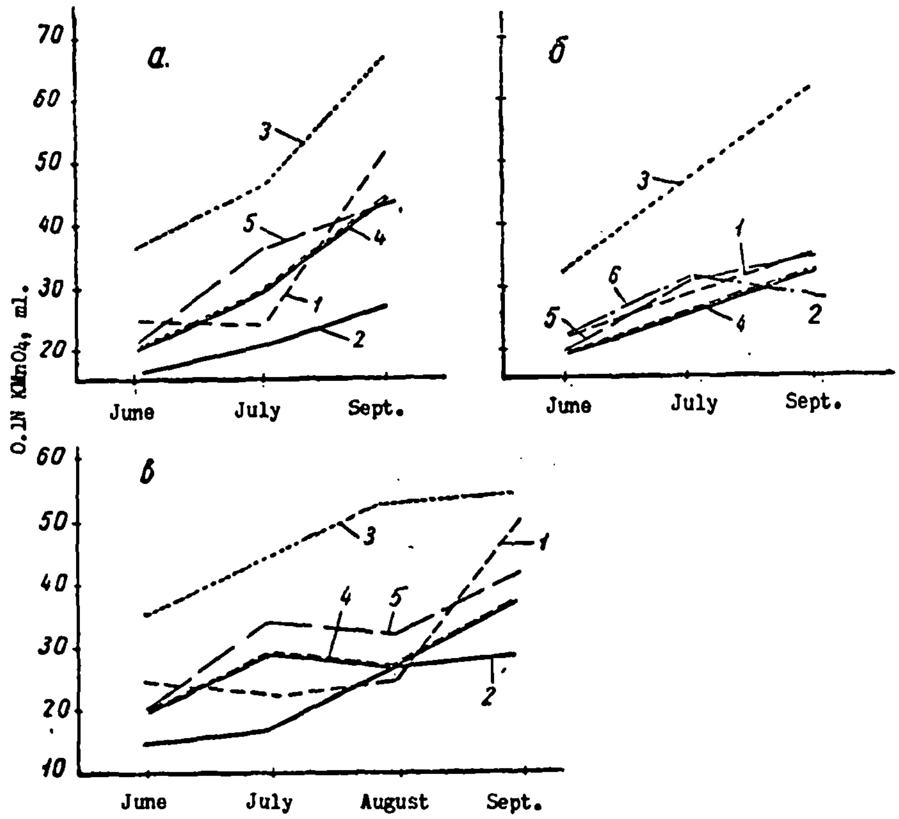

Fig. 7: Change in the amount of leaf substances oxidized by a 0.1N solution of $KMnO_4$ per g. of green weight.

(a) Public park, clear; (b) forest, clear; (c) public park, cloudy.

(The arbitrary numbers are the same as in Figure 1.)

To ascertain the reliability of the data obtained, we determined the amount of oxidizable substances in the poplar and the crab apple, conducting tests with ten repetitions. Statistical analysis of these data makes it possible to note that the average error of the arithmetical mean is

±1.5 ml., and the accuracy of the experiment is within the limits of ±1.3 to 2.1% (crab apple = ±1.3%; poplar = ±2.1%).

Consequently, the data obtained by this method are fairly reliable and possess sufficient accuracy for the purpose of our investigations.

It is self-evident that with only 4 repetitions (Figure 7 and Table 2) the accuracy will be lower. To avoid random errors in the data analyzed for each day of the experiment we grouped the data obtained on a monthly basis and derived the average values. Thus, the average data in Table 3 are derived from 5- to 7-day determinations.

Table 3 : Fluctuations of the amount of oxidizable substances in the leaves during the day - for the growing period of 1960

Species	Amount of oxidizable substances per g. of green weight, mg. 0.1N $KMnO_4$					
	at 7 A.M.	at 1 P.M.	at 7 P.M.	Average amount of oxidizable substances	Amplitude of fluctuations in the amount of oxidizable substances per day	Fluctuations, % of daily average amount of oxidizable substances
			Public Park, June			
Box elder	16.2	18.2	19.1	17.7	2.9	16.4
Balsam poplar	20.7	22.5	24.1	22.4	3.4	15.4
Aspen	21.7	24.3	23.4	23.1	2.6	11.3
White birch	26.3	30.6	28.4	28.4	4.3	15.1
Siberian crab apple	37.3	37.5	41.7	39.2	4.4	11.2
			Public Park, July			
Box elder	18.8	17.3	18.4	18.2	1.5	8.2
Balsam poplar	28.2	28.6	29.8	28.9	1.6	5.6
Aspen	34.3	33.8	38.2	35.4	4.4	12.4
White birch	24.2	19.7	28.0	24.0	8.3	34.5
Siberian crab apple	47.7	43.7	45.4	45.4	4.0	8.8
			Public Park, September			
Box elder	29.1	26.8	25.6	27.2	3.5	12.9
Balsam poplar	43.5	37.8	42.2	41.2	5.7	13.8
Aspen	43.2	47.6	42.4	44.5	5.2	11.7
White birch	48.6	53.3	44.5	48.8	8.8	18.0
Siberian crab apple	50.6	69.9	60.4	60.3	19.5	32.4
			Average Data for the Growing Period			
Box elder	--	--	--	--	2.64	12.4
Balsam poplar	--	--	--	--	3.57	11.6
Aspen	--	--	--	--	4.06	11.8
White birch	--	--	--	--	7.15	22.6
Siberian crab apple	--	--	--	--	9.13	17.5

It is evident from the average monthly data in Table 3 that significant fluctuations in the amount of oxidizable substances can be observed during the day. The smallest fluctuations are observed in the box elder and the greatest in the crab apple and the birch.

In the balsam poplar in July, a substantial decrease in the amplitude of the fluctuation of the amount of oxidizable substances can be observed. This can be explained by the effect of considerable gas damage and by the decrease in the intensity of photosynthesis in July to 7.5 mg. CO_2 per dm^2/hour as against 11.9 mg. in June.

Parallel with the absolute figures of fluctuations of the amount of oxidizable substances, the relative numbers of these fluctuations are given in the table as a percentage in relation to the arithmetical mean.

The percentage of fluctuations in the amount of oxidizable substances in the leaves indicates that these fluctuations are 2-10 times or more greater than the experimental accuracy (2.1%). Therefore, the fluctuations during the day in the amount of oxidizable substances in the leaves of arboreal species are explained by the intensity of physiological processes: photosynthesis, respiration, and other factors.

A comparison of the average monthly data for photosynthesis (Table 2) with the fluctuations in the amount of oxidizable substances during the same months leads to the conclusion that the box elder, which is more resistant to gases, is characterized by a decreasing intensity of photosynthesis and respiration. At the same time, it has the lowest amount of oxidizable substances in its leaves and the smallest amplitude of fluctuations of this during the day. Birch and crab apple, which are not resistant to gases, are characterized by the highest intensity of photosynthesis and respiration and also by considerably larger amounts of oxidizable substances and a greater amplitude of their fluctuation in the leaves during the day.

According to the average data for the growing period, the species most resistant to gases are characterized by a smaller amplitude of fluctuations of the amount of oxidizable matter and by smaller amounts of this matter.

The concentration of dry matter in the leaves (Table 4), which was derived by the refractometric method, varies in the box elder between 9.3 and 12.7%, 14.3 - 21.4% in the birch, and 19.5 - 23% in the crab apple. Therefore, the box elder, which is more resistant to harmful gases, is characterized by a reduced concentration of the dry matter. In the nonresistant species of birch and crab apple, the concentration of this matter is 1.5 to 2 times greater than in the box elder. In the young birch leaves (August 1 and 4) the concentration of dry matter is lower than in the old leaves, which correlates well with their higher gas resistance. During the summer the concentration of dry matter in the leaves increases.

In the forest trees, the concentration of dry matter in the leaves is 1 to 2.5% lower than in the trees of the public park.

The measurement of the pH of the cell contents (Table 4) indicated that in all the public park species the effect of the SO_2 accumulation from the atmosphere causes quite significant decreases of pH. It is of interest to note that in crab apple and birch, which are nonresistant to gases, the decrease of pH in the public park in comparison with the forest is 0.85 - 0.97 while in the somewhat more gas-resistant poplar and aspen, the pH of the cell contents in the public park trees is 0.15 - 0.20 less than in the trees growing in the forest.

During the autumn a noticeable shift of pH to the alkaline side can be noticed in the cell content of all species in the public park and in the forest. This can be explained probably by the irreversible seasonal processes in the aging of leaves of the arboreal plants. In the box elder the lowest pH of the cell contents observed was 4.2 - 4.65. The highest pH of the cell contents is found in the aspen and the birch (6.85 - 6.47).

Table 2 shows the monthly dynamics of the change in leaf damage. If we compare these data with the monthly number of days in which gases from the industrial plant were enveloping the city, then the time relationship of the susceptibility of leaves to gas damage on these days is clearly shown. In the poplar and aspen, the gas damage progressively increases, and in the beginning of August the damaged poplar leaves are shed. The damaged leaves of the aspen do not drop until fall, thereby affecting adversely its ornamental aspects. The damaged box elder leaves turn yellow rapidly, fold up and fall off, but the leaves freshly damaged by the gases are scalded or blighted over no more than 5% of their surface. In the birch the increase in susceptibility to damage during the fall is explained by the replacement of its leaves in the middle of summer.

In estimating leaf damage caused by gases in the individual species, we could not help becoming aware of the shortcomings and inadequacy of the method introduced by N. P. Krasinskiy (1950). This method suggests that in the revised estimation of gas damage, only the percentage of damaged area of the leaves is considered. In comparing the individual species (birch and crab apple), it is often observed that even when leaf damage is approximately the same in surface area it can be quite substantially different with respect to the number of burned leaves expressed as percentage of all the leaves in the crown. The determination of the number of damaged leaves in percentage makes it possible to estimate more precisely the degree of resistance of the individual species and to discover differences not noted at first glance in the resistance of several species with fairly similar susceptibilities to damage.

Conclusions

1. In the box elder, which is resistant to sulphur dioxide, the smaller stoma apertures can be the reason for the decrease in the rate of gas exchange and can thus contribute to the reduction of the susceptibility of the leaf to damage by poisonous gases.

2. In all the arboreal species investigated (box elder, balsam poplar, aspen, white birch and Siberian crab apple) under exposure to harmful gases (SO_2, F), a reduction, in various degrees, of the stoma apertures is observed as autumn approaches. With the absence of the gases, the reverse effect is observed.

Table 4: Concentration of dry matter in the leaves and pH of the cell contents

Species	Concentration of dry matter, %				pH of cell contents			
	at 7 A.M.	at 1 P.M.	at 7 P.M.	average for the day	at 7 A.M.	at 1 P.M.	at 7 P.M.	average for the day
June 27, Public Park								
Box elder	9.3	9.3	10.8	9.8	--	--	--	--
Poplar	17.5	19.0	19.5	18.6	--	--	--	--
Aspen	18.0	19.7	19.5	19.1	--	--	--	--
Birch	18.6	21.4	18.5	19.5	--	--	--	--
Crab apple	19.5	11.8	19.0	20.1	--	--	--	--
August 1, Public Park								
Box elder	11.8	11.7	13.7	12.4	--	--	--	--
Poplar	15.8	18.4	17.2	17.1	--	--	--	--
Aspen	20.5	18.8	17.4	18.9	--	--	--	--
Birch	14.3	14.7	14.9	14.6	--	--	--	--
Crab apple	21.5	21.1	21.1	21.2	--	--	--	--
August 4, Public Park								
Box elder	11.8	12.7	11.8	12.1	4.8	3.9	3.9	4.2
Poplar	20.0	17.8	20.0	19.2	5.8	5.2	5.8	5.6
Aspen	18.4	19.1	19.8	19.1	6.4	5.9	6.2	6.2
Birch	16.1	16.5	14.3	15.6	5.2	5.3	6.0	5.5
Crab apple	20.2	22.3	19.8	21.1	5.2	5.2	5.8	5.4
September 4, Public Park								
Box elder	13.2	12.7	12.5	12.8	4.6	4.6	4.7	4.6
Poplar	19.3	16.8	18.4	18.1	6.4	6.4	6.3	6.3
Aspen	16.7	19.0	17.8	17.8	6.6	6.8	6.5	6.6
Birch	16.8	19.2	16.0	17.3	6.0	--	6.9	6.9
Crab apple	21.5	23.0	20.7	21.7	6.0	6.2	5.9	6.0

3. The amount of easily oxidizable substances in the leaves of arboreal species has been found to be a function of their resistance to acid gases. In the more resistant species (box elder), the amount of these substances is lower than in the heavily susceptible to damage species (crab apple, birch).

4. The amount of easily oxidizable substances in the leaves of arboreal species increases 1.5 to 2 times as autumn approaches, which correlates with the increased susceptibility of the leaves to damage by gases.

5. In arboreal species the magnitude of the fluctuations during the

day in the amount of easily oxidizable substances upon exposure to gas emissions is related to the intensity of photosynthesis and respiration. In the more resistant species, small fluctuations (2 to 4 ml.) in the amount of easily oxidizable substances are characteristic; in the less resistant species, these fluctuations are greater (8.5 to 19.5 ml.).

6. The resistance to acid gases of the arboreal species studied depends upon the intensity of photosynthesis and respiration. In the box elder, which is more resistant, a lower intensity of photosynthesis and respiration is observed.

7. The gas resistance of the species studied appears to be correlated with and depended upon the total water content in the leaves. For arboreal species resistant to gases, a higher water content of the leaves is characteristic.

8. From among the arboreal species studied the species box elder, which is resistant to gases, has been found to have during the summer the lowest concentration of dry matter in the sap of the leaves killed by steam.

9. Under the effect of acid gases, the pH of the cell contents of the leaves decreases. The decrease of pH is a function of the gas resistance of the species: a larger decrease of pH occurs in the less resistant species than in the more resistant.

10. Under the effect of the gases, an accelerated aging of the leaves occurs; this causes an earlier termination of growth in the species under periodic exposures to gas emissions in comparison with those trees not affected by the gases.

11. The study of the physiological processes in the leaves showed that these processes enable us to judge the degree of resistance of arboreal species to gases. Moreover, the physiological studies are conducive to clarification of the reasons for the variations in susceptibility to leaf damage in arboreal species.

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THE ACTIVITY OF CERTAIN ENZYMES

AND GAS RESISTANCE OF WOODY PLANTS

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The nature of the chemical action of sulfur dioxide on green plants is still not clear. The known hypotheses (Noack, 1924; Krasinskiy, 1950) give only general ideas concerning the mechanism of the damaging action of photodynamic oxidation processes. Many have observed that sulfur dioxide in weak concentrations inhibits photosynthesis while not affecting respiration (Thomas and Hill, 1937; Kroker, 1950); others have shown that it at first lowers respiration and then increases it (Wieler, 1905); and still others have reported that respiration, under the influence of sulfur dioxide gas, increases or remains constant (Krasinskiy, 1950). Our investigations (Nikolaevskiy, 1964) have shown that, with noticeable plant damage, photosynthesis ceases, while respiration is intensified several times in light. These apparent contradictions are probably owing to the fact that the respiration was studied on plants that were exposed to different intensities of sulfur dioxide. According to the literature, sulfur dioxide may be considered an inhibitor of the dark reactions of photosynthesis. The works of Thomas and Hill (1937) confirm this view, and have shown that weak concentrations of sulfur dioxide gas influences photosynthesis in the same manner as does a passing cloud. After removal of the action of the gas, photosynthesis returns to normal. There is still little information in the literature concerning the role of enzyme systems in gas resistance. The first and not-so-successful attempt in this direction was undertaken by N. P. Krasinskiy (1937). It seems improbable that such an active anion [sic] as sulfur dioxide would not exhibit an influence on oxidation-reduction enzymes. It is true that, owing to its precipitating action on proteins, sulfur dioxide gas occupies one of the first positions in a series of lyotropic anions (Maksimov, 1958). According to the notion of A. L. Kursanov (1940), during the precipitation of the plant's proteins, the bond is broken in the enzyme-protein complex and the hydrolytic enzyme activity is increased.

It has been shown that plants in the process of ontogenesis undergo a change in terminal oxidase (Turkova, 1963), which could be represented by various enzymes: cytochrome oxidase, polyphenol oxidase, peroxidase, and others. Their role is to assist in accomplishing the final stage of respiration -- the union of the hydrogen of the oxidized substrate with the acid. The above mentioned enzymes, in addition to dehydrogenases, are most often considered in a study of the relation of respiration to the phenomenon of plant resistance to various unfavorable environmental conditions.

The resistance of plants to abiotic factors is related to the lability of metabolism (Sisakyan, 1940). At present, several types of plant respiration are known; glycolytic, hexosemonophosphatic, and several others. There is evidence, for example, that apotome respiration plays an important role in the resistance of plants to infections (Rubin, 1960). It can be supposed that the roles of the first-mentioned two types of respiration will be different in relation to gas resistance.

We have studied the activity of peroxidases and polyphenol oxidases as described by A. N. Boyarkin (1951, 1954) and catalases according to the method of A. N. Bakh and A. I. Oparin (which was borrowed from Val'ter et al., 1957) on leaves of the box elder tree Acer negundo L. (resistant to sulfur dioxide gas) and of the European birch Betula verrucosa L. (non-resistant to sulfur dioxide gas). The dynamics of the activity were investigated during the course of two months (July, August). Also studied was the effect of different concentrations of sulfur dioxide gas on the susceptibility of plants to injury in relation to enzyme activity.

During the summer the leaves of box elder are characterized by a low catalase activity and a high peroxidase activity, while in the case of birch the reverse was true, that is, there was a high activity of catalase and a low peroxidase activity (Fig. 1). This agrees very well with data (Mikhlin, 1960; Turkov, 1963) that indicate a higher activity of catalase during the lower activity of peroxidase. During the fall, the birch begins to exhibit polyphenoloxidase activity, while the elder displayed this phenomenon later.

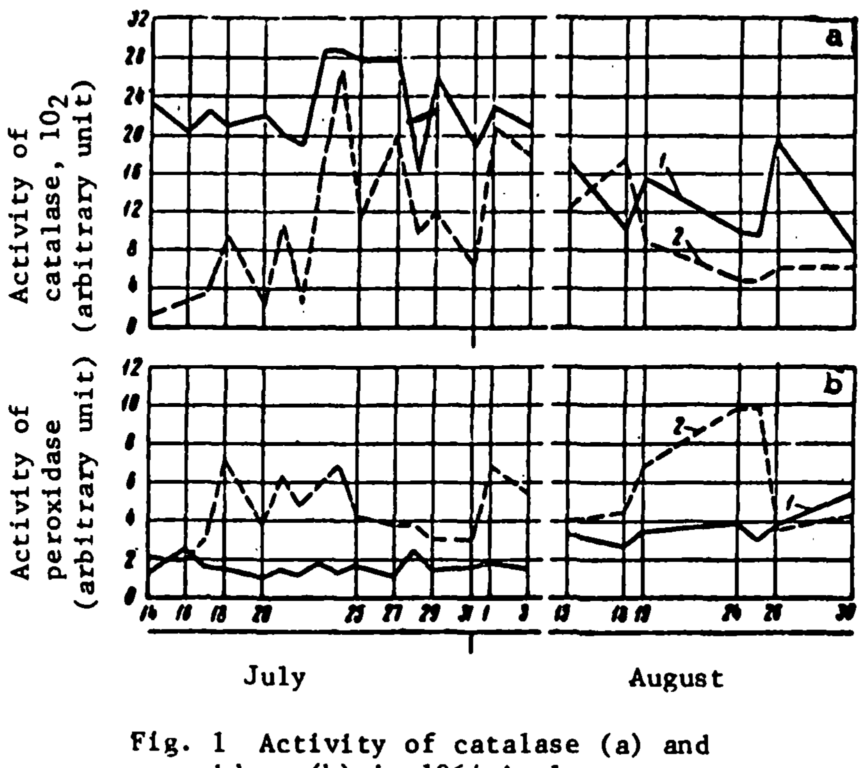

Fig. 1 Activity of catalase (a) and peroxidase (b) in 1964 in leaves.
1 - common birch; 2 - box elder

In experiments with artificial fumigation of foliated branches of the box elder and common birch by sulfur dioxide, interesting data were also obtained. In Fig. 2 is represented the change of enzyme activity under the influence of sulfur dioxide gas in relative indices (percent of control). Depending on the concentration of sulfur dioxide gas and the susceptibility to injury, the activity of the two enzymes of the elder and birch was changed in different ways. In the elder, a weak concentration of sulfur dioxide gas induced a slight decrease in catalase activity and a corresponding increase in the peroxidase activity. The birch, under the influence of those same concentrations of sulfur dioxide gas, showed a significant decrease in catalase activity, but peroxidase activity remained almost constant. With an increase in susceptibility to injury, the two mentioned enzymes of these species underwent a change in activity. The activity of the catalase never achieved its peak level. This is in agreement with the data (Ostrovskaya, Bershteyn, 1953; Mikhlin, 1960) concerning the decrease of catalase activity of plants under the influence of the anions. The activity of peroxidase in birch under the influence of sulfur dioxide at first slightly decreased, then sharply increased (at injury of 50% and more) and again decreased. The increase in peroxidase activity in the elder began earlier (at 20% injury). In Fig. 2, it is apparent that plants having different degrees of gas resistance react differently to sulfur dioxide gas. These phenomena are evident

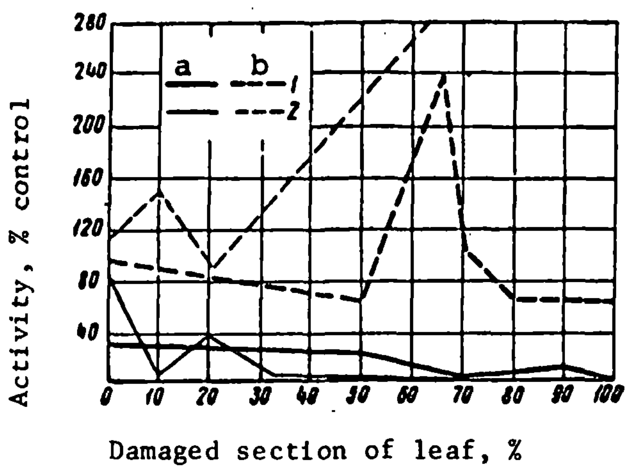

Fig. 2 Influence of sulfur dioxide gas on the activity of catalase (a) and peroxidase (b) on the day of fumigation of the leaves.

1 - common birch
2 - box elder

even if injury is not obvious. Furthermore, according to the character of the curves of enzyme activity, it can be assumed that the elder possesses more labile enzymic systems than does the birch. A similar conclusion was drawn by us earlier on the basis of studies of the water regime and anatomical structure of leaves (Nikolaevskiy, 1964). At the end of August, a significant increase in activity of polyphenoloxidase (from 6-13 times) under the influence of sulfur dioxide was observed.

The nature of the simultaneous study of activity of the two enzymes (catalase and peroxidase) and of the degree of leaf injury allows for a supposition of their mutual interdependence. It is known that peroxidase cannot replace catalase (Mikhlin, 1960), but published data indicate that the activation of peroxidase may be connected with catalase inhibition.

In the presence of weak or unseen damages, the activity of enzymes on the second and third day after fumigation again approaches normal. With high injury (upward of 20-30%), the activity of the catalase on the second and third day remained constant or continues to decrease. At the same time, the activity of the peroxidase in the box elder, after three or four days, returned to normal, but in the birch continued to decrease.

Conclusions

1. Arboreous plants differing in gas resistance (box elder and common birch) are characterized by differences in seasonal dynamics of enzyme activity (catalase and peroxidase).

2. Under the influence of sulfur dioxide, even with unseen leaf injury, there occurs a change in enzyme activity. The weakening of the enzyme system is more critical for the less resistant species -- the common European birch.

3. Sulfur dioxide inactivates catalase and in a determined interval of susceptibility to injury, the activity of peroxidase and polyphenoloxidase increases.

4. The activation of peroxidase apparently enables plants to resist poisoning by peroxides.

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VARIATION IN THE OXIDIZABILITY OF THE CELL CONTENT AS ONE OF THE INDICATORS OF GAS RESISTANCE IN PLANTS

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Introduction

According to our calculations, there is at the present time information concerning the gas resistance of more than 450 species and varieties of trees. There is, however, considerable divergence in the determination of the degree of gas resistance of individual species and varieties, and particularly of the widespread ones. This impedes the practical use of these data. The contradictions are particularly great within the limits of a genus. While the spruce and the fir are considered by all the authors as of low resistance, and the yew and arborvitae of high resistance, the equally widespread genera such as pine, larch, and juniper are sometimes subject to contradictory views. Still more confused is the picture of the deciduous trees.

Similar contradictions are found also within a species. Thus, among the coniferous species the widely distributed Austrian pine and Mugho Swiss mountain pine are considered by some authors to be very gas-resistant; by others, moderately resistant, and by still others as only slightly resistant. The same holds true in regard to broad-leaved trees. Thus, the summer oak, white willow, Norway maple, Tartarian maple, black alder, common lilac, balsam poplar, and black poplar are considered by some authors as the most resistant and by others as the least resistant species.

A step in the right direction was the division of the injurious gases into groups according to their effect on plants, and the selection of plants for such groups. Thus, V. Krocker (1950) subdivided the gases into physiologically active, slightly injurious (ethylene, propylene, and carbon monoxide), and injurious (hydrocyanic acid, mercury vapors, sulfur dioxide, ammonia, chlorine, and hydrogen sulfide). N. P. Krasinskiy (1937) separates acid gases (sulfur dioxide and sulfur trioxide, chlorine, and hydrogen chloride) and non-acid gases (ammonia). Adams and Pullmann (1956) as well as N. D. Thomas (1962) consider that the greatest damage to plants is caused by sulfur dioxide, fluorine-containing compounds, and smog. There are also other groupings.

The selection of plants according to their reaction to the pollutants gave interesting data in many cases. According to the studies of the K. D. Pamfilov's Academy of Municipal Economy, blackthorn and Virginia birdcherry showed greater resistance to chlorine than to other gases, whereas silverberry and woollyleaf mock orange were less resistant (Kuntsevich and Turchinskaya, 1957).

Part of this investigation was devoted to the study of gas resistance within a species. Special attention was devoted to elucidating the effect of various ecological and weather conditions on the vulnerability of plants, and, to a lesser degree, to the gas resistance of plants as it relates to the daily and annual life cycle and to general ontogenesis of woody plants.

Thomas and Hill (1935) along with other investigators (among them our own N. P. Krasinskiy) considered that the toxicity of sulfur dioxide is largely attributable to its reducing properties.

N. P. Krasinskiy (1937, 1950) suggested differentiation of three kinds of gas resistance in plants: biological, morphological-anatomical, and physiological. According to his point of view the effect of smoke gases should reflect particularly on cells having a greater oxidizability of their water-insoluble substances, i.e., the basic components of the protoplasm. In gas-resistant plants the oxidizability of the cell content is lower and in gas-sensitive plants it is higher.

M. A. Zheleznova-Kaminskaya (1953) considered the extent of total oxidizability of the cell content basic in the selection of gas-resistant coniferous plant material for the city of Leningrad. M. D. Thomas (1962) pointed out the changes in the gas resistance of plants during a day and noticed that the leaves are sensitive to the action of sulfuric anhydride in the morning. N. P. Krasinskiy (1950) found that in the course of growth the total oxidizability usually increases with the age of the leaf.

There are indications of changes in the resistance of trees depending on their age. Thus, 50 to 80-year-old Norway maple, oak, aspen, and linden were less damaged than 5 to 10-year-old trees (Krasinskiy, 1937). Pelz (1956) noted conversely that young trees are less damaged than old or middle-aged ones. We have also found greater resistance of young common pine in plantings in the Chelyuskintsev part of the city of Minsk.

Experimental Part

In setting up the investigations we decided to elucidate the variability of the physiological gas resistance in diurnal, annual, and life cycle of the plants' growth and development, in order to establish periods of greater or lesser gas resistance. Here we are presenting preliminary data, which are largely still under investigation. The research started in 1960. The method used by N. P. Krasinskiy (1950) was utilized to determine the total as well as the differential oxidizability of the cell content. Analyses were made at an average of 10-day intervals and the phenophase in the plant development was then fixed by the method of the Botanical Institute. During the spring samples were taken more frequently. Nine species (5 broad-leaved and 4 coniferous) 25-30 years old were used in the experiments. The selected species grew predominantly on the grounds of the Central Botanical Garden of the Belorussian Academy of Sciences. Of the gas-resistant (so considered by many authors) broad-leaved species we used the Eastern poplar and of the coniferous -- the Colorado spruce. Of the low-resistant broad-leaved species littleleaf linden, red ash, and pubescent birch were used; of coniferous -- the Norway and the Eastern white pine; and the English oak, about whose gas resistance there are contradictory opinions, was also used.

In the 1960 experiments carried out with broad-leaved trees, it was noticed that in the determination of oxidizability in the first half of the summer the filtration of the extract took only several minutes, whereas the same operation in the second half of the summer took several hours. This is explained by the accumulation of starch. Keeping the leaf extract exposed to air caused its oxidation and consequently led to errors. Thus, in the Eastern poplar the oxidizability of water-soluble substances after 20 hours decreased to 1/3 and that of the water-insoluble substances to 1/2. In the red ash there was some increase. In the English oak and littleleaf linden the oxidizability of water-soluble substances in the middle of the day rose somewhat and then dropped insignificantly. The oxidizability of water-soluble substances gradually declined and reached 25% in 24 hours, regardless of whether the extract was kept in light or in the dark. This shows that the change in oxidizability cannot be ascribed to photoreactions. As the method of the investigation was refined, the change in oxidizability of the cell content was studied in relation to developmental phases of the plant and in relation to weather and soil conditions. No appreciable variations in the oxidizability of the cell content were observed in connection with weather conditions (sunny or cloudy skies, or sleet), except that the oxidizability of water-soluble substances in the pubescent birch growing on poor soil rose by 30% during sleet. It is noteworthy that this was not the case with birches growing in rich soil. In the case of red ash growing in rich as well as in poor soil, the oxidizability of water-soluble substances in the same day dropped by approximately 15%. Soil conditions had no significant effect on the oxidizability of the cell content of littleleaf linden, red ash, and Berlin poplar. The variations did not exceed 5%.

The most interesting data (see Table) were obtained in determining the differential and total oxidizability of cell content in the various developmental phases of the plant in the course of a growing period. The least oxidizability was observed in leaves in their initial development stages (L^2 and L^3) before they reached normal size and maturity. As the leaf matures, the oxidizability, particularly of the water-insoluble substances, increases rapidly. The maximum is reached in the English oak and pubescent birch when all the leaves attain normal size and maturity (L^5 and L^6). In the red ash, Eastern poplar, and littleleaf linden the maximum is reached during the time from the onset of leaf turning to complete yellowing of leaves. Then the oxidizability of the cell content drops rapidly but does not reach the initial level characteristic of the period when leaf buds open.

In the course of a growing period the oxidizability of both water-soluble and water-insoluble substances nearly doubles in littleleaf linden, Eastern poplar, and English oak. In the red ash, the oxidizability of the water-soluble substances increased more than three times; in the pubescent birch it increased less significantly.

Average total and differentiated oxidizability of cell content of leafy species at various developmental stages of the leaves in 1961.

Oxidizability	L^2	L^3	L^4	L^5	L^6	LT^1	LT^2	LT^3	LD^1	LD^2	LD^3	average
Littleleaf linden												
Water-soluble substances	1.28	1.63	1.8	1.8	2.1	2.2	2.5	-	-	2.2	2.0	1.94
Water-insoluble substances	2.35	2.73	3.47	3.9	4.15	5.15	5.7	-	-	5.25	4.5	4.13
Total	3.63	4.36	5.27	5.7	6.27	7.35	8.2	-	-	7.45	6.5	6.07
No. of determinations	4	8	8	4	8	8	4	-	-	8	4	T-56
Eastern poplar												
Water-soluble substances	1.22	1.46	1.85	-	2.1	2.4	2.0	1.7	-	-	-	1.81
Water-insoluble substances	2.12	2.5	2.75	-	3.4	4.0	3.5	2.85	-	-	-	3.01
Total	3.34	3.96	4.60	-	5.5	6.4	5.5	4.55	-	-	-	4.82
No. of determinations	8	8	16	-	12	4	4	8	-	-	-	T-60
Red ash												
Water-soluble substances	1.13	1.86	1.9	-	2.1	2.35	2.8	2.65	-	-	-	2.11
Water-insoluble substances	1.75	4.1	5.4	-	5.7	5.9	6.0	5.15	-	-	-	4.85
Total	2.88	5.96	7.3	-	7.8	8.25	8.8	7.80	-	-	-	6.96
No. of determinations	4	8	12	-	12	8	4	8	-	-	-	T-56

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(Continued)

Average total and differentiated oxidizability of cell content of leafy species at various developmental stages of the leaves in 1961.

Oxidizability	L^2	L^3	L^4	L^5	L^6	LT^1	LT^2	LT^3	LD^1	LD^2	LD^3	average
					Pubescent birch							
Water-soluble substances	-	1.56	-	-	1.78	1.5	1.3	1.2	-	-	-	1.46
Water-insoluble substances	-	4.78	-	-	5.43	4.0	3.8	3.5	-	-	-	4.3
Total	-	6.34	-	-	7.31	5.5	5.1	4.7	-	-	-	5.76
No. of determinations	-	12	-	-	32	4	4	4	-	-	-	T-56
					English oak							
Water-soluble substances	1.13	1.5	1.7	-	2.3	-	-	-	2.12	2.0	1.75	1.78
Water-insoluble substances	3.25	5.81	6.1	-	6.56	-	-	-	4.5	4.14	3.75	4.91
Total	4.38	7.31	7.8	-	8.96	-	-	-	6.26	6.4	5.50	6.69
No. of determinations	4	8	4	-	16	-	-	-	12	4	8	T-56

L^2 - leaves in growing state; L^3 - leaves of normal size, not yet mature; L^4 - leaves mature, yet not of normal size; L^5 - most of leaves mature, on upper part of shoots, still young leaves; L^6 - all leaves of normal size and maturity; LT^1 - appearance of autumn coloring; LT^2 - approximately half of the leaves turned; LT^3 - all leaves turned; LD^1 - onset of leaf drop; LD^2 - approximately half of the leaves dropped; LD^3 - most of the leaves dropped.

The oxidizability of the cell content of conifers was studied throughout the year. The lowest total differential and oxidizability were found in year-old needles, it was somewhat higher in two-year-old needles, and the highest in older needles. Needles in their first year of life have the lowest oxidizability, and it gradually increases until the growth of the needles is complete.

Variations in the extent of oxidizability during the growth period were observed in the needles from the first to the last year of their growth. During the summer, a period of greatest photosynthesis in the needles, an increase in the oxidizability of the cell content was observed in the Colorado spruce; the increase was greater for the water-insoluble substances than for the water-soluble. Toward autumn, when photosynthesis activity of the needles slackens and the old needles begin to drop off, the oxidizability decreased to 30% in the needles of all ages. With the advent of cold, it again increases to an extent exceeding that of the summer period. A certain relationship between the temperature of the air and oxidizability was observed. Thus, in January 1961, the temperature in Belorussia was very low (down to -40°C). During that period the oxidizability was very high, it decreased somewhat with increasing temperature and remained stable until spring.

The oxidizability curve of water-insoluble substances of the Eastern white pine is very similar to that of the Colorado spruce; however, its oxidizability in the summer period is appreciably higher than in winter. In January it shows a great increase in oxidizability. The oxidizability of water-insoluble substances remained almost constant throughout the year, except for short periodic increases in summer and winter.

The Scotch pine and the Eastern white pine have much in common, except that in the former in December there was a sharp drop in the oxidizability of water-insoluble substances by almost a third and then a sharp increase -- more than twofold -- reaching a maximum in the middle of January, followed by a gradual increase. These fluctuations in the oxidizability of the water-insoluble substances are most pronounced in the two-year-old needles.

Discussion of Results

From the above it is clear that if oxidizability of the cell content be accepted as an indicator of gas resistance of plants, then it is necessary to consider the constantly changing gas resistance. There are some indications of a connection between the fluctuations of the processes within the plant and changes in its surrounding environment; this relation, however, requires further study. It is quite possible that underestimation of the phenophase through which the plant was passing caused contradictory data on conifers presented by M. A. Zheleznova-Kaminskaya (1953). According to her data, the oxidizability of the cell content of the needles in the different species of the Pinaceae cannot serve as an indicator of their gas resistance. Thus, in Abies sibirica Ldb., Pinus sylvestria L., and Pinus peuce Gris., the oxidizability of the cell content is relatively low, and yet, these species are not gas-resistant; indeed, N. P. Krasinskiy (1950) considers the Scotch pine a nonrecommended species. M. A. Zheleznova-

Kaminskaya points out that the high gas resistance of the larches cannot be explained by physiological gas resistance because the oxidizability of the cell content in the larch needles is highest of all conifers.

N. P. Krasinskiy (1939) brought out the question of the effect of the age of leaves on the total oxidizability. He pointed out, in particular, that in the needles of the conifers the total oxidizability increases with age (according to his data it is higher in the needles of the preceding year than of the current year). We have shown that with age there is particularly an increase in the oxidizability of water-insoluble substances. According to N. P. Krasinskiy, it is these substances that are dominant in determining the gas resistance of plants.

N. P. Krasinskiy cites a number of investigations of total oxidizability in leaves of various age of essentially herbaceous plants. Time of taking samples is not stated but it is known that they were always taken in the morning (1950, p. 88). This apparently accounts for the contradictory recommendations made by him. Thus, in 1937 he included among the gas-resistant species European privet, and in 1950 he placed it among the non-resistant. Silverberry and hedge cotoneaster were placed by him in 1937 among the recommended species and in 1950 in the nonrecommended group, and so on. In the numerous determinations on which Krasinskiy based his conclusions concerning the relation between gas resistance of plants and their systematic position he did not take into account changes in oxidizability. This possibly is the reason for the considerable fluctuation in oxidizability within an individual genus, which Krasinskiy indicates.

Apparently, N. P. Krasinskiy did not consider the results that he obtained to be reliable, because the selection of plants recommended by him for use in industrial areas is chosen on the basis of visual observations of a large number of industrial enterprises and on the basis of laboratory experiments with smoke exposure rather than on the basis of determining the oxidizability of the cell content.

Seasonal variations in the oxidizability of the cell content observed in trees is in agreement with the observations of Bobrov (1955) made on Kentucky bluegrass. He suggests the use of bluegrass as an indicator of air pollution by industrial gases and notes that the greatest injury is sustained by mature leaves with reactive stomata. Old and young leaves are less susceptible to smoke.

Conclusions

1. Changes in the oxidizability of cell content and, particularly, of water-insoluble substances is connected with the developmental phases of leaves.

2. Life activity of plants is connected with an increase in the oxidizability of the cell content, and a lowering in life activity of the plant leads to a decrease in its oxidizability.

3. In conifers there is a connection between air temperature and the oxidizability of the cell content, and particularly, of the water-insoluble substances.

4. Acceptance of the oxidizability of the cell content and, particularly, of its water-insoluble substances as an indicator of the degree of gas resistance of plants should take into account considerable variations.

5. Selection of woody plants should take into account the duration of the gas resistance period of the particular species in the course of its growth. The duration of distinct phenophases of the plant could serve as an indicator of such periods.

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EFFECT OF SULFUR DIOXIDE ON THE ENZYMATIC ACTIVITY OF TREE LEAVES

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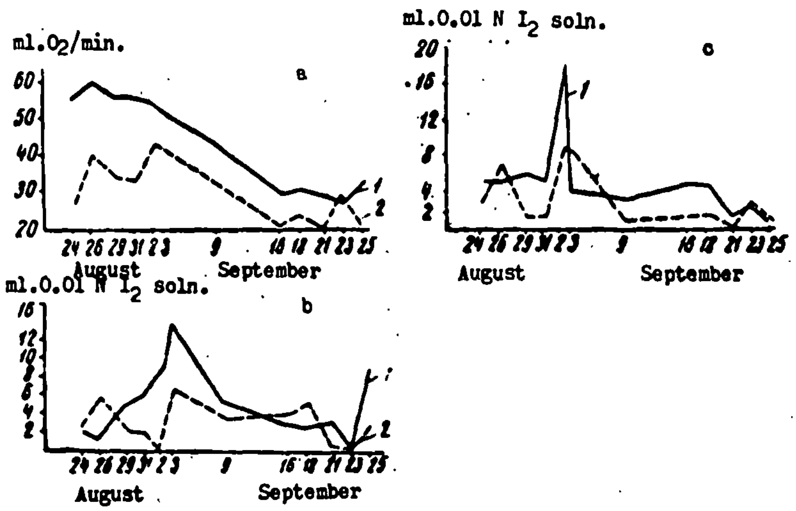
Many investigators (Thomas and Hill, 1937; Krocker, 1950) noted that sulfur dioxide in weak concentrations disturbs photosynthesis without affecting respiration. Wieler (1905) pointed out that SO_2 first depressed respiration and then heightened it. N. P. Krasinskiy (1950) thought that under the influence of SO_2 respiration either does not change or that it increases.

Our investigations (Nikolaevskiy, 1962, 1963, 1964) have established the relationship between the gas resistance of woody plants and the intensity and direction of physiological and biochemical processes within their leaves. A study of the various forms of resistance led to the conclusion that the resistance is determined on the one hand by a group of factors connected with the anatomical, physiological and biochemical properties of the plants and on the other hand by the degree of resistivity and of lability of the metabolism under adverse conditions.

In the five varieties of studied trees: ash-leaved maple, balsam poplar, aspen, Siberian crab apple, and European white birch, a correlation was established between gas resistance, lowered intensity of photosynthesis and respiration, and a lower oxidation-reduction potential. This relationship may be explained by the fact that a decrease in the intensity of gas exchange and metabolism is generally connected with a decrease in enzymatic activity in plants (Siskyan, 1954). When photosynthesis is blocked or stopped, the adsorbed solar energy finds a natural outlet in the oxidation of the constituent and reserve organic substances and components of the cell. Considering that most of the enzymes have reversible properties (Kursanov, 1940; Oparin and Gel'man, 1952), great damage should be expected in plants with an increased enzymatic activity under normal conditions.

The varying effect of SO_2 on photosynthesis and respiration of plants leads to the assumption that not all of the enzyme systems are affected by the action of acid gases. The photodynamic action of chlorophyll under the influence of SO_2 and of the cessation of photosynthesis, established by Noack (1924) and N. P. Krasinskiy (1940), leads to the assumption that under such conditions some photosynthetic reactions in the dark are inhibited. Light reactions occurring upon accumulation of light energy are apparently not affected by SO_2. A study of the effect of SO_2 on the enzymatic activity of plants will, in our opinion, help in the understanding of the essence of biochemical processes causing plant damage.

In 1963 we have studied the activity of catalase, peroxidase, and polyphenol oxidase in ash-leaved maple and in European white birch. The choice was motivated by the substantial differences in their physiological, biochemical, and anatomical indices as well as by their reaction to acid gases (Nikolaevskiy, 1962, 1963). In the terminology of N. P. Krasinskiy (1950 b) ash-leaved maple belongs to the slightly affected varieties, while the white birch belongs to the greatly damaged varieties. The activity of the enzyme was studied from August 15 to September 25. For the same period the effect of various concentrations of SO_2 on the same enzyme was also studied. In all, 14 fumigations were applied, in which the concentration of SO_2 was $2.5x10^{-4}$ and $2x10^{-5}$.



Enzymatic activity of plants:
a- catalase; b- peroxidase; c- polyphenoloxidase.
1.- European white birch; 2.- ash-leaved maple

Catalase was studied gasometrically, peroxidase and polyphenol oxidase by the D. M. Mikhlin and Z. S. Bronovitskaya (1949) method. Leaves for analysis were collected at 9 A.M. from the same trees, on the southern side, from the middle of the crown. The trees were 15-18 years old. Fumigation in the gas chamber was carried out on cut twigs. As control, twigs placed in tap water alongside the gas chamber were used. Analyses were repeated 2-4 times.

On the graphs are given changes in the enzymatic activity of ash-leaved maple and white birch during August and September 1963. Catalase activity in the maple was lower than in the birch by 32.5%. Approximately the same difference was noticed in the activity of peroxidase and polyphenol oxidase in the same species. Taking into consideration that enzymatic activity (Sisakyan, 1954) as well as physiological properties (Ivanov, 1946) in plants constitutes characteristics of a species, we may clarify the possible causes of the relationship between the gas resistance in plants and the intensity of photosynthesis. In our view, the differences in the enzyme activity in the maple and in the birch confirm the assumption that the intensity of photodynamic oxidation under the influence of SO_2 and of light is proportional to the oxidation-reduction activity of enzyme systems in plants. Indeed, ash-leaved maple is characterized by a lower intensity of its gas exchange and of the

Changes in the enzyme activity of tree leaves under the influence of sulfur dioxide

Plant	Absolute activity averages for August-September			Results of fumigation of trees with SO_2											
				Concentration of SO_2 2.5×10^{-4}						Concentration of SO_2 2×10^{-5}					
				Experiment			Control			Experiment			Control		
	Catalase	Polyphenol oxidase	Peroxidase	Catalase	Polyphenol oxidase	Peroxidase	Catalase	Polyphenol oxidase	Peroxidase	Catalase	Polyphenol oxidase	Peroxidase	Catalase	Polyphenol oxidase	Peroxidase
								First day after fumigation							
Maple	29.4	3.5	3.3	10.2*/38.1	2.3/175.0	2.9/98.0	26.8/100.0	1.6/100.0	3.0/100.0	29.5/85.2	5.1/79.6	1.0/38.5	34.7/100.0	6.4/100.0	2.6/100.0
Birch	43.5	4.6	4.7	4.5/9.8	5.3/108.0	4.2/150.0	45.8/100.0	4.9/100.0	2.8/100.0	34.4/78.6	6.7/125.3	2.1/105.0	43.8/100.0	5.3/100.0	2.0/100.0
								Second day after fumigation							
Maple	-	-	-	8.6/29.8	2.5/66.0	1.7/58.7	28.9/100.0	3.8/100.0	2.9/100.0	27.0/76.5	1.5/71.4	2.8/165.0	35.3/100.0	2.1/100.0	1.7/100.0
Birch	-	-	-	2.7/6.0	3.2/78.0	1.8/82.0	44.8/100.0	4.1/100.0	2.2/100.0	34.3/86.8	3.4/141.0	1.8/69.0	39.0/100.0	2.4/100.0	2.6/100.0

* Numerator — absolute value; denominator — percent of control.

activities of the three studied enzymes (see Graph), and consequently by a lower vulnerability. Undoubtedly, the differences in the adsorption rates of acid gases by the leaves of the maple and of the birch (Nikolaevskiy, 1963) are also determining factors.

Experiments with artificial fumigation of twigs in a gas chamber (see Graph) showed that the activity of the three enzymes changes under the influence of SO_2. Particularly clear disturbances were observed in catalase. Decline in the activity of catalase in the maple and in the birch is connected with their vulnerability. Small concentrations of SO_2 ($2x10^{-5}$) caused in both species similar changes in the activity of catalase. Definite changes under the influence of SO_2 took place in the activity of the other enzymes. High concentrations of SO_2 caused an increase in the activity of polyphenol oxidase in the maple and of peroxidase in the birch. On the second day of fumigation, the activity of all the three enzymes dropped in both species. Small concentrations of SO_2 ($2x10^{-5}$) cause no externally apparent damage to the maple and birch but lowered the activity of catalase and affected the activity of the two other enzymes.

There are certain differences in the action of small concentrations of SO_2 when compared with the effect of high concentrations. In this case, the maple exhibited decreased activity of all three enzymes on the first day and an increased activity of peroxidase on the second day.

In the birch, on the first day, along with a drop in the activity of catalase occurred an increase in the activity of the two other enzymes. And on the second day, unlike in the maple, the activity of polyphenol oxidase increased and that of peroxidase dropped. The inhibiting role of anions, and particularly of SO_2 is indicated in the literature (Mikhlin, 1960; Kokina, 1939).

Data in the table lead to the assumption that decreased activity of catalase under the influence of SO_2 is likely to contribute to an increase in the oxidation processes and to the damage of plants (Mikhlin, 1960) because of accumulation of organic peroxide.

There is no clear understanding of the effect of SO_2 on other enzymes. It may be assumed that the nature of the effect of SO_2 on enzymes will be different in plant species characterized by differences in gas resistance. Further studies are needed to elucidate the role of different enzyme systems on the gas resistance of plants.

Conclusions

1. Leaves of the ash-leaved maple and those of the European white birch differ not only in their anatomy and physiology but in the activity of some oxidative enzymes as well.

2. A clear proportional connection with injury to leaves by SO_2 is established in the case of catalase. Great vulnerability of birch leaves is connected with a greater decline in its catalase activity, when compared with the maple.

3. The effect of small and of large concentrations of sulfur dioxide on enzymes differ. In the former case the activity of the three studied enzymes increased on the second day following fumigation, while in the latter case it dropped.

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