Soil technological and other ecological aspects of state of trees in Moscow

O.V. Makarova

Promotor:	prof. ir. U.D. Perdok Hoogleraar in de bodemtechnologie
Co-promotor:	dr.ir. A.J. Koolen Universitair hoofddocent, Leerstoelgroep Bodemtechnologie
Promotiecommissie:	prof. ir. K. Kerkstra, Wageningen Universiteit prof. dr. agr. J. Müller, Wageningen Universiteit prof. dr. S. Schütz, Universität Göttingen, Duitsland dr.ir. J.H.M. Wösten, Alterra, Wageningen

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PREFACE

Urbanization is one of the main social-economic problems of our days. In the majority of countries cities have become overcrowded with population, overloaded with industrial products and as a result it causes intensive urban pollution. Non-utilized industrial and municipal waste with toxic chemical elements is the main source of pollution. In the majority of industrial cities one can notice the superposition of different industrial pollution areas and types of communal activity, also the forming of technogenic geochemical anomaly in the components of urban landscape (air, snow, soil, surface and underground water) is observed. As a result a city is becoming more and more complex, unstable and often a dangerous environment for plant-raising. So no wonder that in many cases the state of urban green is unsatisfactory.

To my son Dimitri

1. LOCATION AND DESCRIPTION OF THE STUDY AREA

1.1. Climatic characteristics of Moscow region.

The Moscow region according to forest zoning is situated in a coniferous-broad-leaved forest subzone of a mixed forest zone and belongs to a forest vegetation district – a pine forest with admixture of fir-trees (spruce-trees) and broad-leaved species. Table 1 shows parameters of Moscow region climate.

Table 1. Parameters of region climate (Lihachova, 1990)

Items	Unit of measurement	Point	Date
1. Air temperature:			
Average annual	C	+ 3,5	
Absolute MAX		+ 35	
Absolute MIN		- 48	
2. Amount of precipitation a year	mm	549	
3. Duration of the growing period	Days	151	
4. Frosts:			
last spring frosts			13 May
first fall frosts			20 September
5. Average date of river freezing			17 November
6. Average date of the spring floods beginning			14 April
7. Blanket of snow:			
depth	cm	15	
time of cover			17 November
time of vanishing in forests			5 April
8. Soil freezing depth	cm	50…90	
9. Direction of the predominant winds:			
Winter	Compass point	SW, SE	
Spring		NW	
Summer		W	
Fall		W, SW	
10. Average speed of the predominant winds:			
Winter	m/sec	4,4	
Spring		4,2	
Summer		3,4	
Fall		4,3	
11. Relative atmospheric humidity	%	80	

Among the climatic factors which have a negative influence over the growth and development of forestry vegetation one should mark late frosts, which beat down young tree shoots and reduce seed yield; strong wind, which cause windfall of fir-trees, especially on soils with excessive moistening; strong snowfall with simultaneous thaws, which cause snowbreak in pure thick fir and pine saplings; and strong frosts in January and February, together with summer heat in some years.

Cultivation of mixed plantations of optimal composition, which are most weather resistant, can help to reduce negative influence of climatic factors.

On the whole the regional climate is quite favourable for the growth of pine, fir, birch, larch, aspen, oak and alder trees as proved by the existence of better tree conditions. Only an extreme departure from the climatic norm presents some danger to the development of young vegetation, but it happens very rarely.

1.2. Special features of the Moscow city.

Moscow is an ancient city with the law-governed nature so characteristic of all great cities. At the same time Moscow has some specific features which distinguish it from other ancient largest cities including European ones.

To its general phenomena first of all one should ascribe the interaction of the city and the local climate in the process of which the city first adapts itself to the climate and then changes it actively forming common environment of its inhabitants.

Moscow among other European capitals has its own absolutely special position. Climatic processes demonstrate the contrast and significant amplitude of temperature, humidity and radiation characteristics. Northern processes and phenomena which make it comparable with the cities of northern Europe (Helsinki, Oslo, Copenhagen) are characteristic of Moscow as well as some southern features. Aqueous geological environment formed with sediment in contradistinction to rock and semirock (Paris, Madrid, Rome), flatness of the landscape, abundance of surface water, unsteady small-leaved types of vegetation with considerable admixture of coniferous forests, inconstancy of wind conditions in direction, speed and strength parameters testify to rather low natural potential of self-cleaning and as a result of the dependence of the natural features on the interference type and its intensity. The city itself is that kind of interference. Any interference in the geological environment and break of the natural flow change moist regime and further in line influence the vegetation state, which in its turn influences the state of the surface air. Precipitations on the contrary more actively than in southern cities cause instability of the hydrological regime and influence the stability of the geological environment.

Thus the distinctive feature of Moscow as one of the world largest cities is the tight connection of human influence on the nature and its response, irreversability of the process and rapid loss of the self-regeneration quality of the natural components. The ability of climate regeneration is Moscow's specific feature that has been observed for years.

The ecological situation of Moscow also depends on the state of its suburbs, the degree of development of the plant recreation system. The areas of nature preservation are at the same time the areas of preserving of recreation resources. Within the 5-7 km limits nearby the ring road there is less greenery then in the peripheral Moscow districts. It can be explained by the fact that local meteoconditions are not taken into consideration during mass construction and after it bald ground is left, the natural complex (small rivers, forests, landscape) vanish having no time for adaptation. Round the constructing outskirt districts, which transform the territory, a desertification zone is forming.

Moscow is situated at about 55^o-56^o north latitude and 37^o-38^o east longitude, it is interpositioned between the Oka and the Volga in the centre of the geological basin, formed during the coal period. Within Moscow limits there is a number of hills: Borovitsky, Sretensky, Tverskoy, Tryohgorye at Presnya, Vorobiovs, Taganka and Lefortovo. Moscow territory is considered to be a plain. Its main part is 30-35 m above the Moskva river level (about 150 m above sea level). There is some relief elevation at the flood-lands terraces of the Moskva. The highest part of Moscow – Teplostansky hill is situated in the south and south-west of the city, it is 250 m above sea level. Leninsky hills, its northern part, are 80 m above the Moskva river level. To the north of the city there is the northern slope of the Klinsko-Dmitrovskaya range of 180 m height. Tatarovsky hill is in the north-west.

The lowest part of the city is the riverine of the Moskva river (116-117 m) and also eastern and south-eastern outskirts with a part of the Meshcherskaya lowland, which is 120 m above sea level.

The length of the Moskva river within the city limits is about 80 km, which makes a 35 km bee-line between the city boundaries.

The Moscow climate is temperate-continental. There is neither severe frost nor excessive heat in Moscow. Absolute minimum of temperature in recent 80 years (-47^{o}) was fixed only once and only at one meteorological station in Tushino district. As the city is growing the difference between Moscow and near Moscow climates is becoming more significant. On clear frosty nights it is $2\text{-}3^{o}$ C (sometimes even 6^{o} C) colder in the suburbs. The average winter temperatures in Tushino, the coldest district of the capital, are: in December – $7{,}7^{o}$ C, in January – $10{,}3^{o}$ C, in February – $9{,}7^{o}$ C. In Balchug street (the warmest street of the city) the average temperature of June is 17^{o} C, of July is 19^{o} C and of August is $17{,}4^{o}$ C. In recent 80 years the average annual temperature at the boundaries of Moscow hasn't changed ($3{,}8^{o}$ C), but it has grown up to $4{,}8^{o}$ C in the centre of the city. In Moscow the temperature above zero averages 194 days a year and the temperature below zero - 103 days. The sun shines 1568 hours a year.

On the whole the Moscow climate is changeable. Departures from the norm are quite often. Prolonged thaws happen in December. During years there had been averagely 4 days a month in December, with the temperature indices above zero. Sometimes summer heat suddenly turns to fall in temperature and lingering rains. According to ancient Russian chronicles it snowed sometimes in July and frost spoiled rye in early July. In 1485 January and February were so warm that trees blossomed in the gardens and birds began to build nests.

Ascending flows of comparatively warm urban air with great amount of aerosol often contribute to cloud forming or compression and hence influence the atmospheric precipitation regime. On the whole the atmospheric precipitation regime over the Moscow territory is illustrated by the following parameters. Within Moscow the average perennial precipitation sums make 575-600 mm a year including 375-425 mm during the warm period and 175-215 mm during the cold period. The amount of precipitation differs a lot from year to year: now there is a lot of precipitations (up to 900 mm), now there isn't (less than 300 mm). The fluctuation of this parameter is especially considerable in warm periods.

About 15-20% of precipitation amount falls in solid state. During cold periods (November – March) the precipitations are on the whole solid. During warm periods (April – October) the precipitations are on the whole liquid and total about 60-70% of the sum a year. On transition months (March – April and October – November) and when there are thaws in winter mixed precipitations prevail (wet snow mixed with rain, frosty rain, etc.) and make 10-15% of annual amount.

1.3. Geological structure and relief

The Moscow region is situated in the central part of the vast Russian plateau, formed with massive thickness of sediment deposited on a crystalline basis (foundation). The Contemporary relief is determined by Pre-Cambrian foundation/formation, which has a complex structure with large hollows and raisings.

Different geological factors took part in forming of the relief: tectonic forces, erosion processes and glacial activity.

During the glacial period the region three times suffered icing. The Dnieper icing occupied the whole regions territory and moved forward to the south far out of the region limits. The glacier changed the relief radically and then formed the thickness of glacial deposits. The moraine extended all over the region territory, only in the river valleys its wholeness was ruined.

The Moscow icing, which happened later, occupied only the northern part of the region and only in the south-east it moved a bit farther to the south than Moscow latitude. The quarternary icing and waterflow erosion played an important part in the forming of the modern relief.

Thus concurrent with glacial and water-glacial forms of relief there is a number of developed erosion forms of relief that resulted in flat surface of ancient moraines. The main features of the macrorelief were formed during PRE-Quarternary period. Contemporary mesorelief indicating the natural territory division into 3 parts and hydrographic net was formed during Quarternary period.

The geomorphological processes of the city territory are an insufficiently studied section of geomorphology, a science that studies reliefs. The town-planning has to deal with natural processes – erosion, landslip, karst, etc.

The three groups of contemporary geomorphological processes were defined for the city territories: the first group – natural exogenous (external) and endogenous (deep) processes, the second – natural processes and phenomena changed by the human activity in quality and quantity, the third – processes and phenomena occurred as a result of man-made activities, engineering and communal.

The second group includes both natural and technogenic processes and the third – only technogenic. The technogenic processes in its turn may be divided into two types: direct and indirect. The direct technogenic process is industrial human activity that changes the relief without any participation of natural relief forming processes. Let us denote them as technogenic denudation and technogenic accumulation. Technogenic denudation is the soil excavation for structure constructions (foundation pits), building materials and mineral extraction in open-pit mines (open-cast mines, sand-pit, hollows cavities), the relief leveling for constructions, etc. And technogenic accumulation means embankments, additional pouring, dumps, settlings, etc.

Very often direct technogenic processes changing the relief, especially during the construction of large hydrotechnical objects, are of complex character – both technogenic accumulation and denudation. These technogenic forms of the relief can be small, but this kind of activity is directed to change the relief, the hydrosystem, the catch basin, the river waterfullness, etc. In nature this kind of changes occur only as a result of catastrophic phenomena – earthquakes, volcano eruptions, glacierization, etc.

Purposeful relief changes are of short duration as a rule, but they form the conditions different from natural for a long period, which often exceeds the term of the territory exploitation for practical purpose.

The conditions for further development of natural technogenic and indirect technogenic processes occur. Indirect technogenic processes occur as a result of man-made activity both mentioned earlier (that changes the relief) and the one that doesn't set such objects. The city territory exploitation comprises static, dynamic, heat, chemical, electrical and biological impact on the geological environment. Additional soil watering and pollution through the communication leakage, draining through melioration and drainage, artificial soil compaction and some other kinds of impact should be added. All that causes uneven ground sinking, damage to constructions, communications, foundations, pipe corrosion, subsurface and ground water pollution. These and some other processes are named technogenic.

One would think that the process of the relief planning corresponds to the classic scheme of the relief levelling: a peak denudation – slope gentling – valley filling. Only the top link in the chain of technogenic changes can be conditionally compared with natural denudation as top (positive) forms of natural relief as a rule are leveled, and this changed natural relief form is characterised by the thickness of the local (autochthonous) material. But these processes differ sharply in time terms.

1.4. Soil-forming rocks characteristics and soils of Moscow region.

The relief complexity, the variety of quarternary deposits and parent rocks, differentiation by the territory drainage level resulted in formation of a complex soil cover. Because of the district features mentioned earlier there is a great variety of parent rocks and soils on a comparatively small area. The main parent rocks are:

- red-brown Dnieper moraine;
- cover clay and loam;
- fluvioglacial sands;
- ancient alluvial deposits.

The following types of soils are formed from them:

a) soddy-podzolic;
b) soddy-podzolic half bogged soil;
c) bogged soil.

Soddy-podzolic soils prevail. All soddy-podzolic soils are divided into 3 species according to the podzolization level:

1. Soddy-weak podzolic.
2. Soddy-medium podzolic.
3. Soddy-strong podzolic.

1. Soddy-weak podzolic soils cover tops of the hills or ridges with gentle slopes, usually are well drained. These soils are favourable for pine and larch tree growth. There are 70-80 t of humus and up to 15 t of potassium and phosphorus oxide per ha there.

2. Soddy-medium podzolic soils cover flat plain territories or hill and ridge slopes. In chemical composition these soils are richer on the surface loam, less rich– on the moraine and more less – on alluvial deposits.

3. Soddy-strong podzolic soils develop in descents, welldrained relief elements and within the Meshcherskaya low-land – on the loamy soil of more than 80 cm strength with sandy underlayer at the ground water level of 1,5…2,0 m. These soils have different forestry features for different woody plants. Thus pine, birch and aspen trees lower their productiveness on these soils.

Taking into consideration rich variety of existing parent rocks, which significantly increase the number of soils, and presence of complex deposits this territory can be characterised as unique, with complex ecosystem and rich variety of forestry conditions.

By the city soil is meant any soil functioning in the city environment. According to Stroganova (1997) the city soil is the soil with man-made upper soil of more than 50 cm thickness formed by intermixing, filling, burial or pollution with urbanogenic materials. The city soil features the following characteristics, different from the automorphic taiga soil:

- the presence of the filling layers of different strength endows the soil cross-section with laminated constitution and vertical-horizontal variability;
- the presence of the urbo-anthropogenic fractions (construction, consumption and industrial waste);
- the top part of the cross section isn't connected genetically with the bottom part;
- overconsolidation and damage of the natural structure;
- the contrast water regime – flooding caused by ground water and undersurface communications, drying of the upper layers (when precipitation pass the soil), accumulation of atmospheric water in the top layer of the soil cross-section;
- the heat regime – heightened, weak freezing or absence of freezing along heat transmission lines;

- aeration worsening, change of the soil air composition (increasing of carbonic acid amount, decreasing of the oxygen amount);
- heightented stonyness;
- soil alkalinity;
- high level of magnesium and calcium in the soil; accumulation of the technogenic pollutants (heavy metals, salts, pesticides, organic waste, etc.);
- upset of the nutrient cycles and dynamics (leaf gathering off, dead wood and wind-fallen trees moving off, etc.).

The contemporary city soil forming takes place in natural soils, on the cultural layer and in the ground not changed by the soil formation processes or human activity. The cultural layer provides a historically established system of layering, formed as a result of human activity (Saushkin and Glushkova, 1983). Thickness of the cultural layer may range from several centimeters to dozens of metres (up to 12 m in Saratov, up to 22 m in Moscow) and shows up particolouredness even within small areas.

The cultural layer forming goes by surface accumulation of different materials occurred as a result of man-made activity or by transformation of the upper natural layer when constructing or improving the city. The contemporary cultural layer contains different fractions – broken bricks, stones, construction and consumption waste, abandoned foundations, cellars, wells, flooring made of logs and planks, cobble-stone and asphalt pavement. The construction waste usually prevails. All these cultural layers played the role of soil in different historical epochs and under their influence assumed their features. Thus the cultural layer constitutes a system of buried city soils of different age, the paleo-urban soil is among them.

The territory of ancient large cities (Moscow, Novgorod, Kiev and some others) soon may be divided into two main zones: a zone of an ancient settlement with a widely developed cultural layer and formed thick urban soil and a zone of fresh constructions with a weak cultural layer, fresh and old grounds, which contain natural soils with different level of damages, where new weak urban soils are forming.

The whole spectrum of loose sediments and mountain grounds may be found in the city. The ground type and ground mixture effect the soil features, soil forming processes and soil functioning. That’s why in the city soils, as it is indicated by German scientists, the soil features mainly depend on the substrate characteristics.

The city grounds undergo changes at a great depth: the foundations for the surface constructions are laid at 35 m depth, for the underground constructions – up to 60-100 m. It causes not only ground mixing, but it also changes the direction of the subsurface flows and hence the soil-geochemical flows too.

By this means the city soil forming (urban soil, urban technogenic soil) may go in the following way:

a) the soil on the culture layer;

b) the soil on the mixed, filled, silt grounds composed of the organic and mineral soil material (the soil on the mixture of remains of the natural soils);

c) the soil on the fresh filled or silt grounds (the soil on the ground).

The above-mentioned grounds should be divided into pure grounds and toxic ones (containing heavy metals and toxic substances).

Different activity may cause changes in the city grounds: removing, digging up, filling. After filling the ground is particularly loose. When the soil being formed on the filling grounds deep penetration of the organic substances (including some detrimental compounds), nutrients (especially phosphates) and heavy metals is observed, as native soils are enriched only in the upper layers. Silt also occurs in cities, for example, in the Maryino district in Moscow and in the Gavan’ district in St.-Petersburg. Filled and mixed substrates with a great amount of the construction waste are of heightened alkalinity.

The majority of the city soil cross-sections is disturbed, but there is not enough time for the soil-forming process to form “in situ” the genetic cross-section of the soil. There are descriptions of the evolutionary changes which the urban soil cross-section of Western Berlin has undergone for the latest 39 years (Blume, 1989). Fanning et al.

(1978) investigated the structural cambric layer in the 30 years old urban soils of the Washington city and classified these soils as “inseptisalts”.

As it was mentioned earlier (Stroganova, Agarkova, 1992) in spite of the disturbance and artificial origin of the soil cross-section, severe pollution with different fractions the processes of humus-forming, gley-forming, carryover and redistribution of mineral substances take place. The extent of the distinctiveness of these processes differs and depends on the age of the alluvium, the conditions of the plot exploitation and some other circumstances.

At the same time the influence of the main processes, typical for this natural zone, on the soil forming is doubtless. In definite conditions the urban soils developing on the cultural layer or on the grounds evolve into natural soils with typical features and a genetic layer system.

The concept of the city soil which is used by the specialists in the city ecology nowadays comprises not so much the layer morphologic composition as the accomplishment of the definite ecological functions.

1.5. The hydrological conditions.

1.5.1. Moscow region.

The major part of the territory is characterised by the presence of a developed hydrographic net, which provides the natural drainage.

All rivers flow mainly from the north-west to the south-east into the Meshcherskaya lowland. All the rivers of the region belong to the Oka river basin.

The river Klyaz’ma flowing in the north part of the forestry is the largest river of the territory. The river Vorya is one of the largest tributary of the Klyaz’ma. The whole length of it is 108 km, 32 km of which are on the territory of the Shchyolkovsky district. The river Vorya limits the Vorya-Bogorodskoye forestry in the South. In the north-west this territory borders with the largest in the district water-bog formation the

Dushonovsky bog. The largest tributary of the river Vorya within the examined territory is the river Pruzhonka (the Pruzhenka or the Pruzhunka on some maps). This river originates not far from the settlement Malyie Petrishchy, just nearby the forests of the Ogudnevskoye forestry and is fed by the Bezymyanny stream, the rivers Belaya and Belenkaya, which drain the north-west part of the territory. The south-west part of the territory is enriched with lakes and is drained with the streams (rivers) Kozliha and Okonnitsa, which flow into the river Vorya.

The Kozliha originates in Lake Myortvoye. On the map of 1884 there were Romanovsky bogs on the place. Nowadays because of the disturbed hydrologic regime the lake has again turned into a bog. Lake Goluboye (Lake Sineye on the map of the Dolgolugovskoye hunting ground) formed in the place of the Torfyanoye bog. At present there is Lake Tchyornoye (Mohovoye) in the place of the Mohovoye bog. In 1885/87 the peat excavation took place there.

The river Okonnitsa originates in the Goveynihinsky bog of the transitional type, which at present is a part of the state nature reserve "Tumeniha". Behind villages Aksinyino and Alekseevka-1 there are the so- called Kraft bogs and Alekseevsky bogs of the lowmoor type. Some sections of the river Pruzhonka are bogged too.

On the whole streams, lakes, rivers, ponds and drainage trenches cover the area of 30,4 ha. 92,6 ha fall to the share of bogs that constitutes 20% of the total area of bogs on the hunting grounds. There with on the territory of the Vorya-Bogorodskoye forestry three main types of the bogs occur: highmoor (38,5 ha), transitional (1,6 ha) and lowmoor bogs (52,5 ha). The stock of reclamative afforestating land of 198,2 ha is exhibited in the plots, distributed all over the territory. Thus water objects (rivers, streams, lakes, bogs) constitute 2,5% of the observed territory.

Water objects are refuges, dwelling-places and feeding-places for different animals. They maintain specific and quantative variability of biocenoses, serve as regulatores of the water balance, effecting on the feeding and transitional waters, so they are of zoological, hydrological and general ecological importance.

1.5.2. The Moscow city.

The rivers flowing throught the territory of Moscow agglomeration, as it was mentioned earlier, belong to the Moskva river basin. Within the area between western boundary of the Odintsovskoye district (25 km higher than Zvenigorod) and eastern boundary of the Ramenskoye district (15 km lower than Bronnitsy) the Moskva is fed by the two large tributaries: Eestra on the left and Pahra on the right.

The Eastra is 149 km long, the basin area is 2108 km^2, it is fed by more than 20 tributaries. In upper reaches of the Volga at the confluence with the river Nudol the Eastrinskoye reservoir was built – the greatest water reservoir in the Moscow district. Its area is 3360 ha and it is 23 m deep.

The Pahra is 129 km long, its basin area is 2720 km^2. It has a great amount of feeders – about 230 with small rivers and streams. The largest of them are: the Mocha, the Konopelka, the Rozhai, the Desna with its feeders Neznaika and Bitsa. The Moskva is 75 km long within the city boundaries. It forms six large windings there preserving at the same time its general direction and receives a number of feeders. The largest of them are: the Setun, the Gorodnya on the right, the Skhodnya and the Yaouza on the left. On the whole the territory is drained by 46 water flows. The total length of the open river- beds is about 220 km and the length of the collectors is more than 290 km. The total area of the open reservoirs is 8,5 km^2.

The Moscow hydronet has been greatly changed as being under construction. There were bogs and little lakes at the outfalls of some rivers. On the flood-lands banks of the Moskva (Dorogomilovo, Louzhniky, Nagatino) there were many former lake-beds and bogs. With the city growth little streams, bogs and ravines little by little were filled and vanished. More significant rivers were dammed, turned into a chain of ponds and then filled with alluvion. The Moscow construction caused the damage of the groundwater outflow and even of some small river outfalls.

The Yaouza is the largest tributary of the Moskva within the city boundaries. It was polluted severely at the beginning of the XXth century. One could hardly believe that in its place in XIX – XV a full-flowing river ran. It was even prefered to the twisting Moskva. During the years of Soviet Power the Yaouza was cleaned, its flow was added with the water from the Khimkinsky reservoir through the Lihoborsky canal. Due to the heightening of the river level after damming and widening the river-bed up to 25 m the Yaouza became navigable from the mouth to the plant "Krasnyi Bogatyr".

The Presnya originated in the Goreloye bog. Later it was filled with metro construction dump. Filling of the Presnya valley and locking its water into a collector took place in 1908-1915. The Neglinnaya river originated in the Pashenskoye bog (behind the Maryina grove), then they began to fill it with waste and filled it absolutely in the 30th with the metro construction dump 3-5 m thick. The Neglinnaya with its feeders and ponds is well seen on the city plan of Moscow of 1779. There were more than 20 ponds within the Neglinnaya and its feeders in past years. In 1819 the river-bed of the Neglinnaya was locked in a tube and now it is underground. The Samotechny pond and the Verhny Neglinny pond were the largest ponds in the Neglinnaya basin. They were filled in the XVIII century. On the territory of the modern Sverdlov square and Revolutsii square there was a pond till 1812. The Alexandrovsky garden was organised in 1820 till 1823 in the place of the Kremlin ponds on the Neglinnaya. Besides the Neglinnaya and the Presnya there is a number of other rivers locked in brick corridors: the Chertorny, the Sivka, the Olhovets, the Kapelka, the Rachka, the Nishchenka, the Protoka, the Sarra, the Danilovka, etc.

Within the modern boundaries there were 120 rivers and streams, 55 of them were large enough and probably had a constant flow. There were 853 ponds at the beginning of the XVIII century. Now there are about 300 lakes and ponds at the same territory. The major part of the natural reservoirs was reconstructed.

The Moskva as the other rivers of the Moscow region is fed by water from melted snow – 61%, rain water – 12% and ground water – 27%. Usually the ice breaks on it on 10 April. The average duration of flood-time (of high water) is 48 days, minimum – 21 days, maximum – 85 days (1896). Freezing over occurs on 19 November. Within the city centre the river practically doesn’t freeze over because of warm discharge water. The Modulus of flow in the Moskva river basin averages 6,2 km/d. The annual flow totals 3,4 km^3.

2. BASIS ASPECTS OF WORK: A LITERATURE REVIEW

2.1. The state of the Moscow vegetation.

The analysis of the Moscow vegetation showed that the urban trees and shrubs are in a deep crisis. There is a tendency to sharp reduction of the city greenery reserve, reduction of the space assigned for planting, degradation and death of the vegetation. And also the illegal cutting, the impoverishment of the city face, its streets and squares, sharp reduction of the sanitary-hygienic effect from the vegetation are observed. According to the estimated normative indices of the General Plan and General Scheme of planting trees and shrubs in Moscow, adopted in 1970, the public territory of trees and shrubs was to total about 27000 ha by 1990. But in fact it totaled only 8900 ha by that year and the territory reserved for planting was built-up, assigned to garages or turned into waste ground. This tendency had been increasing till the middle of 90-s (Mozolevskaya et. al, 1996).

Crisis phenomena in the vegetation state first became especially evident in 1996 when according to the state report “About the state of the Moscow environment” the death of 250 000 trees was established. Among them 6500 trees which were situated along highways. According to the results of the dead trees cutting analysis done in 1997 the causes and consequences were so complex and multivarious that it is very difficult to analyse the influence of the anthropogenous factors and impossible to take preventive actions. Hence there are no grounds for any optimistic forecast.

It is evident that preservation and increase of the urban territories covered with vegetation, improvement of the quality and composition of the plants in the city parks, gardens and so on are the most effective and comperatively cheap ways of environment management in urban conditions. That’s why in August 1996 Moscow government adopted Resolution 671 “About action for improving the state of the Moscow vegetation”, where the necessity of vegetation state monitoring was first marked (Ecological investigation…, 1998).

At present, Moscow’s greenery reserve experiences quality changes that dictate the need to develop specific solutions aimed at improving the management structure, streamlining measures geared toward greenery restoration, preservation and maintenance at planting facilities. In this connection, the role of monitoring of greenery as a constituent of the municipal system of environmental monitoring surged. In 1998, to implement Decree of the Moscow Government of January 20, 1998, No. 41 Concerning Steps Aimed at Improving the Moscow Greenery Management Structure, Decrees of the Moscow Government Premier of March 31, 1998, No. 348-RP, and of August 31, 1998, No. 987-P, Concerning Planting…, work to develop and operate the Moscow greenery status monitoring system was proceeded with.

Within the framework of the Monitoring Program, the Information and Analytical Center for Planting is functioning efficiently. The Center is tasked with arranging for, and coordination of, greenery status monitoring in Moscow as well as operational information support of work related to the municipal greenery reserve and landscaping, including planting under extraordinary conditions in the city. While implementing the Monitoring Program in 1998, various methodic instructions and practical recommendations on planting and landscaping of the city were provided to facilitate work of the appropriate agencies.

Nowadays, the municipal greenery monitoring network comprises 272 permanent surveillance sites where 46,065 plants were examined in 1997-2000. (Ecological investigations…, 1999).

The 2000 monitoring statistics concerning species composition of trees and bushes on new surveillance sites confirmed earlier published data on the species composition of greenery in planted territories. Basically, the “assortment” of municipal greenery is represented by 15 species of plants. The substantially prevailing species are linden (small-leaved, large-leaved, ordinary), pointed-leaved maple, balsamic poplar, Pennsylvanian ash-trees.

The status of the main species of trees in the city's greenery, in the opinion of many authors, depends, first of all, of their stability in adverse factors of the urban environment. In Moscow at large, the greatest percentage of plants in good state were detected among the examined trees: pointed-leaved maple – 49%, balsamic poplar – 32%, and smooth elm-trees – 35%. Among these species, the percentage of plants in unsatisfactory state was the least vs. other species. The state of small-leaved linden – the most common species in the city – was worse than that of other species but somewhat better than large-leaved linden. In particular, among examined trees of small-leaved linden, the percentage of plants in good state was 27.9%, in unsatisfactory state 26.6%. Among examined plants the percentage of plants in relatively satisfactory state ranged from 30% to 44%, irrespective of species.

Small-leaved linden was found to be in the best state in parks and gardens as well as micro-districts where 48.5% and 32.8% of examined plants were in a moderately weakened state category respectively (relatively good state so far) (Ecological investigations…., 2000).

2.2. Urban soil characteristics.

2.2.1. Location.

Urban soil is a complex of genetically self-dependent soils, which have both natural and specific features (Craul, 1993; Couenberg, 1994; Hollis, 1992; Huinink, 1998; Flemer, 1976; Liesenke, 1991; Physical conditions…, 1955). Adult urban soil (urbana) formed on the ancient cultural layer is characterized by the availability of the massive darkcoloured organic level U (urbic) and lack of the profile alluvial – illuvial differentiation, typical for the taiga soil. The urban soil profile often increases at the expense of dustcovering and incoming antropogenious material.

Main distinction and deterioration of the typical Moscow soil from automorphogenic taiga soils:

1. **Morphological characteristics:**
    - 1.1. Presence of urban-anthropogenic elements (construction, consumption and industrial waste).
    - 1.2. The profile topping isn’t connected with the bottom part.
    - 1.3. High horizontal and vertical veriability.
    - 1.4. Stratified structure and sharp pass from one stratum to another.
    - 1.5. Presence of surface crust when the soil is overconsolidated.
    - 1.6. Presence of series of historical-archeological layers and soils.

2. **Chemical processes and characteristics:**
    - 2.1. Alkalinity, caused by the urban dust and construction waste.
    - 2.2. Carbon pollution.
    - 2.3. Humus composition.
    - 2.4. Violation of the nutrients cycle and dynamics.

3. **Physical processes and characteristics:**
    - 3.1. Compactness – heightened, violation of natural structure.
    - 3.2. Water penetrability – mosaic, locally sometimes very high, sometimes not available.
    - 3.3. Stonyness – heightened.
    - 3.4. Gas regime – change of the soil air and aeration deterioration
    - 3.5. Heat regime – heightened, weak freezing through

3.6. Water regime – contrasting (flooding a little, drying up, precipitation running off the surface)

4. **Biological characteristics:**
    4.1. Biodiversity cutting down, change of the microflora composition, quantity and structure.
    4.2. Mass increase with ecosystem diversity.
    4.3. Forming of the specific biota, presence of pathogenic micro-organisms.

While studying the city and country physical soil characteristics many authors discovered that the city soil differs a lot from the natural one. First of all water-physical characteristics differ a lot (Lichter, 1993; Kochanovsky, 1964a, 1964b; Koolen, 2000; Kopinga, 1985, 1991; Kramer, 1963; Kozlowski, 1982; Soil physical…., 1955).

The following changes of the city soil are found out: compactness, structure changes of the soil levels in the direction of the stratification, forming of large-lamellate elements (Bakanina, 1990a, 1990b; Wopereis, 1981; Xu and Thornton, 1985). As a rule the city surface is rather complicated.

2.2.2. Soil compaction.

According to some findings the soil penetration resistance in the streets of Minsk at the depth of 0-40 cm is 2-3 times higher than in the forest. Especially high resistance is under the trees with prematurely dying leaves (30,5-38,2 kg/cm^2) (Kochanovsky, 1964).

The soil density of more than 2,0 g/cm^3 absolutely blocks up the root development. At the same time the soil density of 1,6 g/cm^3 and less enables the root to develop through the whole profile up to 1 m in depth (Bunt, 1996). Compactness makes the particles lying close to each other move. It causes the reduction of pores in the soil bulk and the root has to change the direction of its development. The mechanical tension also increases from the soil density. In the compact soil the root will be able to move on the condition if the diameter of free pores is more than the root head or about 100 micrometres. So that the root could move further, when the porse are less, it should make the soil elements move slide apart. Its ability to do that depends on the strength the root can apply. The border of the level overcompactness and root breaking begins with the value of 1,4 g/cm^3 for the loamy soil and 1,5 g/cm^3 for the sand soil (Stroganova, 1997).

According to some data the root growth reduces by 50% at 0,7 MPA penetration resistance (7,1 kg/cm^2), by 80% at 1,4 MPA resistance (14,3 kg/cm^2) and stops at 2,0 MPA (20,4 kg/cm^2). Dobson and Moffat (1993) and McAffe et al. (1989) showed that worst of all roots develop at a resistance of 3,0 MPA (30,6 kg/m^2) in spite of clefts which appear in the soil during the droughts. Bakker et al. (1979) showed that root growth was observed through the whole level at a soil compaction (penetration resistance) of up to 20 kg/cm^2 (1,96 MPA), but it stopped at the compaction of 34 kg/cm^2 (3,3 MPA).

Kuzmenko (19350) showed that root growth is limited in a clay soil when the soil compactness is more than 14 kg/cm^2 and in a sand soil when the compactness is more than 1,7 kg/cm^2.

Porosity is one of the remarkable soil features conditioning air and water regimes. Water distribution in the soil, water penetration and water upwelling, water mobility depend on the size of pores. In forest parks, gardens and boulevards, where the soil isn’t exposed to compactness, the porosity varies from 45 to 75% (Ecological investigations…, 2000).The porosity is connected to such important soil characteristics as water and air absorbing ability. With deterioration of water-physical characteristics the accumulation of water in the soil decreases, especially in summer months and makes up to 14% of water absorbing ability in the compacted soils (Stroganova, 1997).

2.2.3. Drainage and aeration.

Deterioration of the poriness and aeration due to high soil density affect soil air and water penetration characteristics (Shevchenko, 1992). It is essential to take into consideration that the surface of gas interchange between the soil and atmospheric air is too small (1,5x1,5 m). In the case if the ground round the trunk is covered with cast iron grating, this surface is reduced by 50-60% still more. As a result after watering and plentiful rains water stands in the holes for a long time blocking for some time the soil gas interchange absolutely. These factors cause accumulation of some extra quantity of carbon and oxygen reduction in the city soil. The author's investigations showed that the volume of the pores, filled with air, is about the same and varies in the city from 16,5 to 24,4 and in the forest from 17,8 to 21,4%. But this parameter can't characterize the air soil regime. In the surface air of the territory with forest vegetation there is 3-6 times less carbon than in the soil of the street vegetation. So at the depth of 20 cm there were average 2,7-6,9% CO_2 and 15,0-18,8% O_2 in the street soil. At the same time there were no more carbon than 1,1% and no less oxygen than 19,3% in the forest soil. Investigations by Kochanovskiy (1964) established that the roots of the trees of 20-30 years old develop not only within the planting hole measuring 1,5x1,5 m. Under asphalt at the depth of 20 cm (1,5-2 cm from the edge of the hole), where there are some more roots, the soil air composition contains carbon of about 10-12% and oxygen of about 7,6-9,4%. But for the normal growth it is essential that CO_2 in the soil air doesn't exceed 2% (Physical conditions …, 1955). Accumulation of CO_2 in the soil air (up to 9-10%) and reduction of O_2 (up to 10-12%) shorten the relative length of active roots 20-30 times (Kochanovsky, 1964).

As is known, aggravation of water and physical parameters of the soil decreases accumulation of moisture in it, in particular in summer. High density of soil may lead to dehydration of lands or create conditions at the root-inhabited layer that are close to anaerobic in the period of long rains and in autumn (Hamilton, 1984a, 1984b; Wilcox, 1968). Under these circumstances, the growth of small (active) roots of trees and grassy plants is made more complicated in the regeneration period (Harris, 1994; Heliwell 1986).

An important feature of urban soils is their capacity to absorb and transmit water coming from the surface. The value and the nature of water permeability greatly change depending on the extent of stoniness, fractional void volume, humidity, granulometric, aggregate and chemical composition, as well as the type of roadway surfacing and the open area around the tree trunk. Slack, or mosaic, water permeability determined by voids in the layer due to construction and household waste is typical for urban soils. Several cases were described in literature when water permeability may be very low (Hodge, 1993).

Therefore, to ensure viability of plants, in particular in urban conditions, there is a great need in creation of an optimal water regime of the soil. Otherwise, in search of moisture, roots will be forced to move across the soil. For instance, it is known that water flows very slowly in the soils with humidity that is lower than field capacity, so water reserves are soon depleted in the root-inhabited soil layer. Water in soils with humidity that is lower than field capacity may only be available with constant elongation and ramification of roots. Unless root systems were elongated, trees would seriously suffer from the lack of water, even though some water was available in the soil at a small distance from the root (Physical conditions…, 1955). The volume of the planting pit is very often limited under urban conditions. Therefore, the roots of plants leaving the planting pit can damage roadway surfacing significantly.

2.2.4. Chemical toxicity.

The city soils are rather different from their natural analogs in main chemical indices. The acidity index of the root level of the city soil varies widely but neutral and weak alkaline soils prevail. (Lepneva and Obouhov, 1990; Ware, 1990). In the majority of cases the city soil reaction (pH) is higher than that of the natural soils. The majority of authors connect the high city soil alkalinity with calcium chloride, sodium and other salts used for pavement de-icing in winter, which get into the soil with surface flow or drainage water. Another cause is the washing of calcium with acid rains out of construction waste which contains alkali: cement, bricks, etc. Practically everywhere the decrease of pH index with the depth is observed.

It is known that the rise in the acidity index up to the neutral level is favourable to the growth of the majority of plants and to the activity of micro-organisms, it also links some soluble heavy metal compounds. But further alkalization can cause the formation of some difficult to solve nutrients and micro-elements and beginning with 8-9 pH index the soil becomes useless for plant growth.

Particularly high pH values are typical for near-trunk tree rounds and lawns situated along highways. According to many authors, the main reason in this case is water soluble salts used in the city as anti-glaze mixture (Bakanina, 1990).

According to some researchers side by side with dust and gas emission easily soluble salts which are used in icy conditions to cover the pavement represent one of the main factors of the vegetation state deterioration in Moscow. During the snowmelting these salts penetrate into the soil and cause its pollution. There are some data that salting takes place within 15-25 m round the road. In Moscow water-salt mixture is usually used as an antiicing agent. As a result the content of sodium in the soil along the highways totals 12-250 mg per 100g. Relatively dry spring heightens the plant pollutant burden. The content of sodium in the soil samples totaled 300-1045 mg per 100 g, of chlorine – 300-1720 mg per 100g. (Ecological investigations…, 1998).

Sodium in the soil mainly has the form of NaCl. The analysis of the salt mixture shows that NaCl totals 97% of the mixture. The results of the water extract from the salted soils displayed that the content of soluble sodium in them 1,2-24 times exceeds the content of calcium and magnesium and the content of ion-chlorine 1,2-7,1 times exceeds the content of hydrocarbonate-ion.

Adding de-icing salt mixtures is a reason of not only salinization of Moscow soils but also to solontzicity of soils, which is very unfavorable for plant growth. Solontzicity is evidenced by the presence of metabolic sodium in the absorbing system of the soil that was discovered in soils by many authors.

Periodic change in processes of salinization (winter, early spring) and de-salinization (summer, autumn) sparks periodic sub-solonetzicity that results in the ever-increasing concentration of metabolic sodium year by year. According to a number of authors, should this regimen be further maintained for a fairly long time, one may state with confidence that the metabolic sodium concentration is likely to reach so high levels as to transform soils in solonetz.

Interesting data is provided by Meyer (1996), whereby the most detrimental impact on the state of plants under urban conditions is made by chlorine-ion rather than by sodium-ion. According to the established standards, for instance, in the Netherlands, no more than 3 grams of water soluble salt NaCl are used per 1 sq. m to combat icing. In Moscow, according to our standards, 50 grams of that salt are used per 1 sq. m. In fact, this figure is much higher (Ecological investigations.., 1999). Therefore, it is difficult to evaluate the impact of a separate ion on the state of urban plantations. However, good understanding of the influence of Na^+ and Cl^- ions, taken separately, on the state of plants will help make a more correct choice of water soluble salt that produces a less detrimental effect on urban plantations, in Moscow in combating icing.

In the opinion of a number of authors, heavy metals (HM) make a detrimental impact on the stability of plantations in Moscow. However, there is no unanimous opinion on the role of each component in change in the state of plantations up to now. There is still controversy around issues of streamlining the heavy metal concentration in soil.

Many authors have failed to establish a clear-cut interdependence between the heavy metal concentration in soils and plants. In their opinion, gas and soil emissions accumulating on the surfaces of leaves make a considerable contribution to pollution of plantations in urban conditions. (Ladonina, 1999).

The influence of soil pollution with heavy metals on the state of microelements in plants depends on the type of soils, species of plants, and growth conditions. Some authors use the notion of “soil resistance to heavy metal pollution,” which is determined by the critical level of the polluting metal concentration when toxic effects are found in plants and in the environment at large, and is intertwined with the cation capacity of soils. As usual, the resistance of non-acid heavy soil with high content of organic substance is several times higher than that of light soil. Loamy neutral soils can accumulate large concentrations of micro-elements with a lower risk for the environment. However, total chemical instability of these soils usually sparks diminished biological activity, fall in pH and consequently, degradation of organic / mineral complexes. Side by side with acidification of the soil the content of heavy metals (lead, copper, zinc, cadmium) rises in the soil bulk as the solubility of HM compounds rises when pH indices are low. HM solving is also possible at the expense of the ion interchange reaction and as a result of failure of unsteady compounds in the acid environment. At the same time the sharp rising of the HM concentration in the soil bulk of the upper levels can be observed at lower pH indices than those of the bottom levels (Sokolova and Dronova, 1993).

Thus, Moscow soils represent a man-caused composition of solid, liquid, and gaseous phases with indispensable participation of the live phase and performing certain environmental functions. A majority of conditions of urban soil formation lead to change in physical and mechanical, water and physical and chemical parameters.

2.2.5. Factors that affect urban vegetation

A tree in natural conditions may grow up to 200 years and more. In the urban environment trees are exposed to more intense stress than trees in the forest or in the field (Brunch, 1976). It is connected with the fact that the trees growing in their natural conditions are adapted to the environmental factors. And in a city trees are planted to improve the face of the city and its ecological norms, but often the conditions are unsatisfactory for normal growth and development. As a result of the wrong choice of the place, type and conditions of planting the trees suffer a surplus or a lack of water, the detriment from salts, heavy metals and other unpopular soil conditions, and air pollution.

That's why in the park environment trees manage to grow up to 80-100 years only. In the street environment trees die out more intensively and the majority of trees die by 50-60 years (Shevchenko, 1992). Urban trees planted along highways and pedestrian zones don't grow up to 30 years. A tree planted into a small finite volume can grow only up to 3-4 years (Perry, 1989).

In Brussels it was established that tree fall during the first year after planting is comparable with the general annual plant death-rate in the city (P. Basiaux, personal communication) In Washington a case is known when only 54% of 5671 planted trees were alive since 5 years had passed after planting.

No doubt, trees in the urban environment are exposed to more intensive stress than trees in the forest or in the field.

There are different opinions of the reasons that cause tree weakening and withering in the urban environment.

Analysing the data reported by many authors and the vegetation state in Moscow it is possible to single out the following main factors that affect the state of the urban vegetation (Bakker et al. 1979; Biddle, 1987; Bassuk and Whitlow, 1987; Blomarz, 1993; Grabosky and Bassuk, 1995; Grace, 1987; Clark, 1989, 1990, 1992; Gibbs, 1994; Ehsen, 1990; Dudly, 1976; Davis, 1976; Ash, 1990; Himmelick, 1976; Rolf, 1994; Rulford, 1992; Ruark, 1983; Nelson, 1976; Struve, 1988, 1993; Lawriel, 1994; Ruan, 1976; Jim,1994; Goncharick, 1962; Martin et al., 1989; Andersen, 1976; Lindsey and Bassuk, 1992; Kopinga, 1985; Low, 1989; Anon, 1991):

1. **Ecological conditions of the city.**
    1.1. Rise of air temperature
    1.2. Decrease of relative air humidity
    1.3. Rise of solar radiation
    1.4. Additional illumination of vegetation at night
    1.5. Decrease of the street ventilation

1.6. High gas-pollution
1.7. Increase of the wind speed in new micro-districts and on the slopes
1.8. Increased ambient noise level
1.9. Existance of underground communications
1.10. Electromagnetic fields

2. **Planting technology.**

    2.1. Quality of the plant material
    2.2. Planting time for trees and shrubs
    2.3. Planting scheme for trees and shrubs
    2.4. Vegetation planting along transmission lines
    2.5. Non-observance of the rules of tree and shrub planting
    2.6. Digging up and transportation of trees and shrubs
    2.7. The quality of preserving trees from transport means, people and animals
    2.8. The type of the tree planting (on a lawn, in the middle of the asphalted or tiles-covered territory, etc.)
    2.9. The volume of the planting hole (the depth of the rich soil)
    2.10. The quality of the soil in the soil bulk of the tree
    2.11. The state of the soil

3. **The state of the soil**

    3.1. The amount of the available water
    3.2. The amount of oxygen
    3.3. The amount of the nutrients
    3.4. Biological activity of the soil
    3.5. The amount of the organic substance
    3.6. Deep freezing caused by the lack of the snow cover
    3.7. Availability of heating mains, causing unfreezing of the soil in winter time
    3.8. High soil compaction preventing root development
    3.9. Soil alkalinity
    3.10. The quality of the drainage and ventilation systems

4. **Accidental factors**

    4.1. Polluting substance
    4.2. Vandalism
    4.3. Physical damage by transport means and people

5. Cost of planting

No doubt all these factors: the climate, gas-pollution of the city, breaking of the planting technology, the quality of the plant material – affect the state of the urban vegetation. But according to many experts just the quality of the urban soils causes 80% of unsatisfactory state of the vegetation. According to their experience the plants growing in good soil environment even in the case of high gas-pollution have good state.

3. DEVELOPMENT OF RESEARCH OBJECTIVES AND FIELD WORK CRITERIA

3.1. Investigation objects, tasks and actuality.

Topicality. Many factors effect size, colour, height, chemism and appearance of plants. Living conditions don't always correspond to plant physical needs. Soil is one of the main factors that have a significent impact on plants. Successful development of woody plants is possible only in the soils with available nutrients and water. To create aesthetically valuable vegetation, resistant to recreational load and other anthropogenic and technogenic detrimental effects, it is important to evaluate woody species and vegetation status to expose main detrimental factors, to evaluate the soil quality and its creative ability.

Main objectives are: to determine a system of informative soil and plant status indices and their interdependence in view of future estimation of the level of water and minerals supply essential to plants; to work out a methodology of complex woody plants status diagnostics, methods and technologies of the plant sustainability control in different ecological conditions; to base these actions on the results of many years of investigations.

To attain the objectives it is first essential to serve the following problems:

- to work out a technology of studying the data on status diagnostics and optimisation of soil-hydrological conditions for woody plants taking into consideration their biological features, the soil fertility indices, the level of keeping the nutrient balance, the water balance status and the plants state;
- to detect diagnostic parameters of the state of urban soils and plants;
- to detect the relationship among parameters of soil quality and the state of urban plants, aiming at further development of methods and technologies of creating optimal soil and hydrological conditions for plant growth.

3.2. Materials and methods.

The city greenery suffers high technogenic stress of pollutants coming from air and polluted soils. A plant is one of the most sensitive indicators of the technogenic city environment changes. That’s why biological methods, based on the response reaction of organisms to technogenic impacts, are widely used for evaluation of the environmental pollution (Ecogeochemistry of the city…, 1995).

Tree type, locations and measuring period. Street line plantations of small-leaved linden (*Tilia cordata*), which were situated in the lawns of East administrative district of Moscow, were chosen as the object of investigations as their state was the most unsatisfactory in comparison with other types of plantations (a public garden, a boulevard, yard plantations, etc.) and as they are wide-spread in the city (Ecological investigations…, 1998) (Fig. 1).

The eastern part of Moscow, the same as its centre, has the worst ecological indices. This territory is highly polluted with HM, chloride contents and other toxic pollutants. Industrial enterprises (metallurgy, machine-building, polygraphy, heat and power plants, etc.) and automobile transport blow out into the environment about 130 kg of pollutants per one citizen a year or 1,22 kg per m^2 of the regions area (Ecological investigations in Moscow and the Moscow region. M, 1990, p. 248). This is the territory of high industrial potential and high population concentration and in addition to that as a result of western atmospheric circulation this territory gets a great amount of additional pollutants from adjoining territories by air (Strogonova, 1997).

Measurements were carried out in the years 1998, 1999 and 2000. A range of preliminary observations were held in the year 1998. The use of these measurements was that expertise was built up on measuring methods and on tree conditions and growing sites of Moscow. The further part of this report applies to the observations from the years 1999 and 2000.

The chosen objects of the 1999 and 2000 investigations were situated in two types of the city ecological conditions: in an ecologically unsuccessful zone (at the centre and some middle part of the city) and also in a relatively ecologically tense zone (in some middle part of the city and in the suburbs) (Fig. 3).

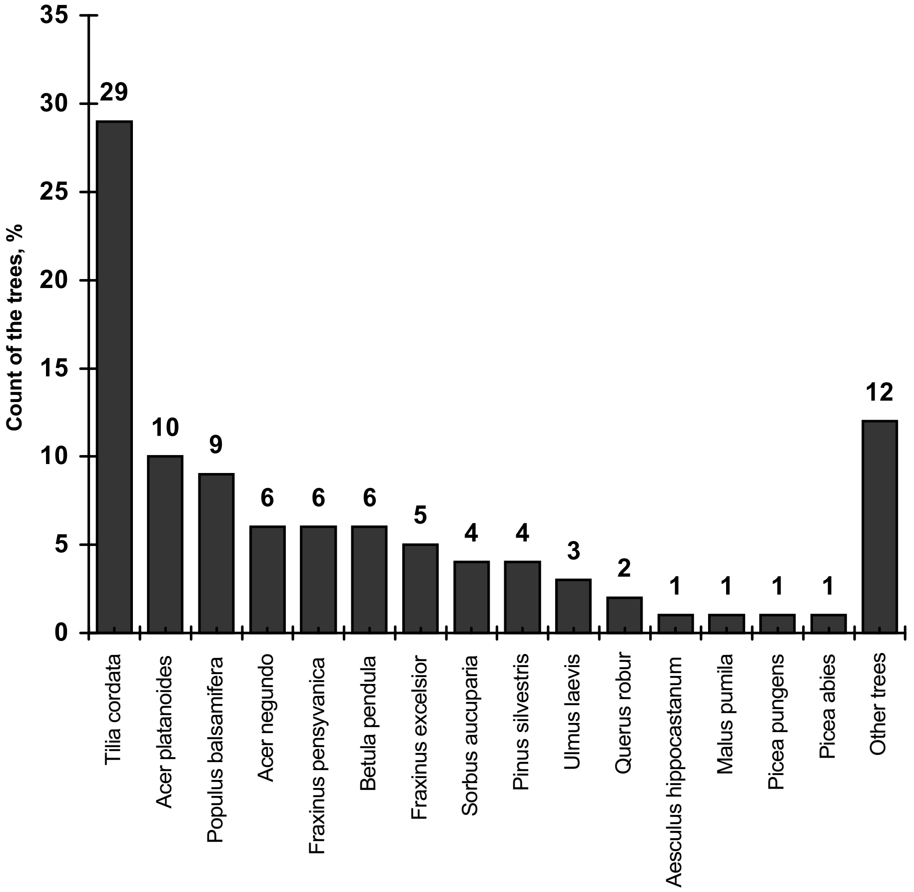

Fig.1 Types of plantations in the Moscow city.

A clearing in the forest in the localities near Moscow was chosen as an object for the absolute control. Lime plantations in the public garden in the suburbs of Moscow (in a zone of relatively successful conditions) served as objects for the relative control. There were totally 15 main objects and about 20 auxiliary ones.

Among them: Object 2 – single lime plantations in grass-plots in Khabarovskaya street; Object 3 – lime plantations in a public garden near Otradnoye metro station; Object 5 – single lime plantations in grass-plots near Sokolniky metro station: Objects 7, 11 – single lime plantations in grass-plots in Prospect Saharova avenue. Object 10 – single lime plantations in grass-plots near Mayakovskogo metro station; Object 9 – lime-trees in the forest clearing near Moscow (Shchyolkovskoye teaching-experimental forestry, Chkalovskoye forestry station, wood lot 12, plot 24). See Fig.2.

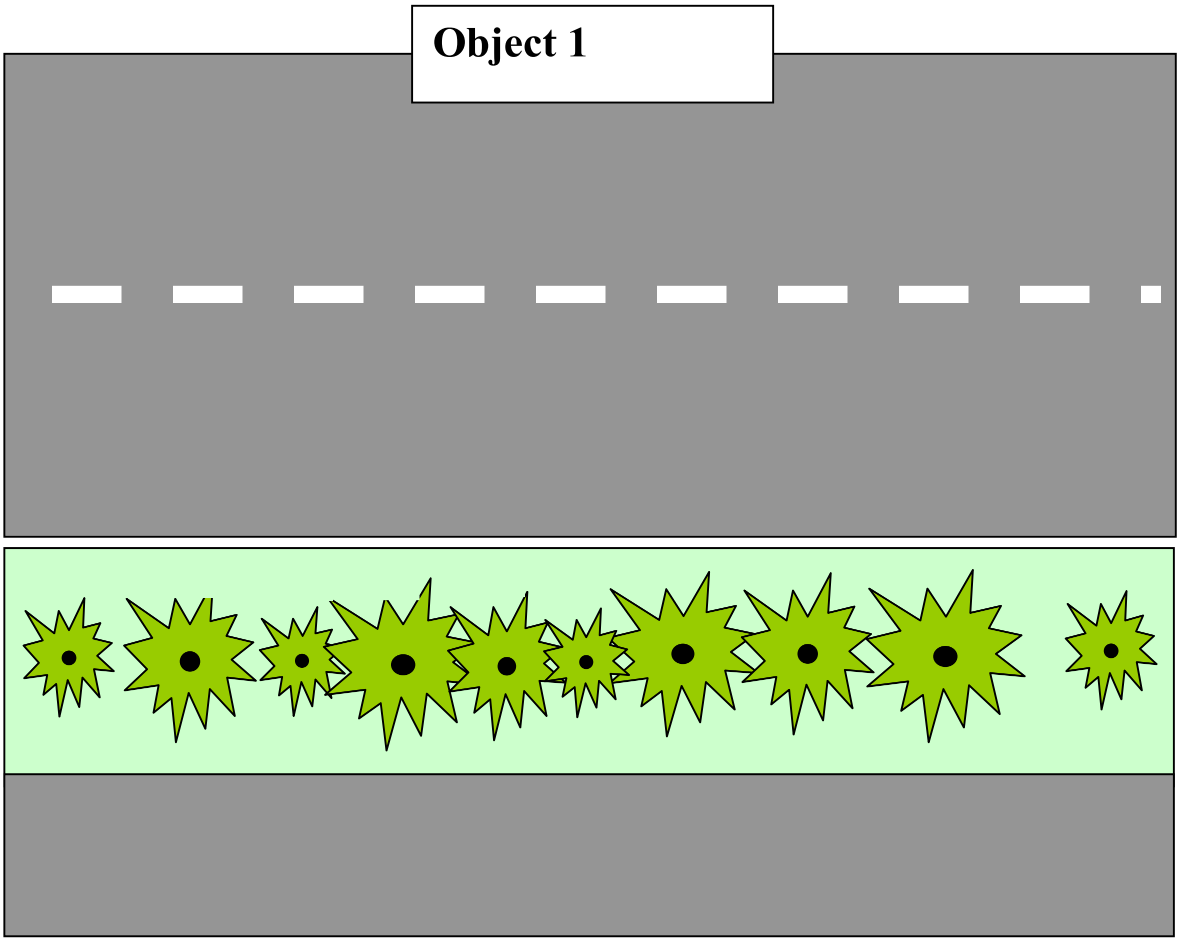

Fig.2. Example of the field experiments. Top view. Line of trees in lawn between a road for pedestrians and an asphalted road for vehicles.

Methods. Each object numbered (many) more than 6 trees. Sample trees were chosen to determine the leaf transpiration and a loss of water in pre-set time intervals after the leaf has been teared off: every 3 minutes (up to 30 minutes) and every hour (up to 5-7 hours). Transpiration indices were determined by the weighing method (with the use of torsion scales) (Skazkin, 1958).

As is known, in addition to daily fluctuations of transpiration depending on many reasons, the intensity of these processes was observed to change in plants during the entire ontogenesis. Therefore, leaves were chosen after the shoots had stopped growing (when the top leaf-bud was formed) from the middle part of the shoot on the southern side of the tree.

Numerous investigations showed that young plants as well as young leaves transpirate more water than old ones. (Romanov, 1955).

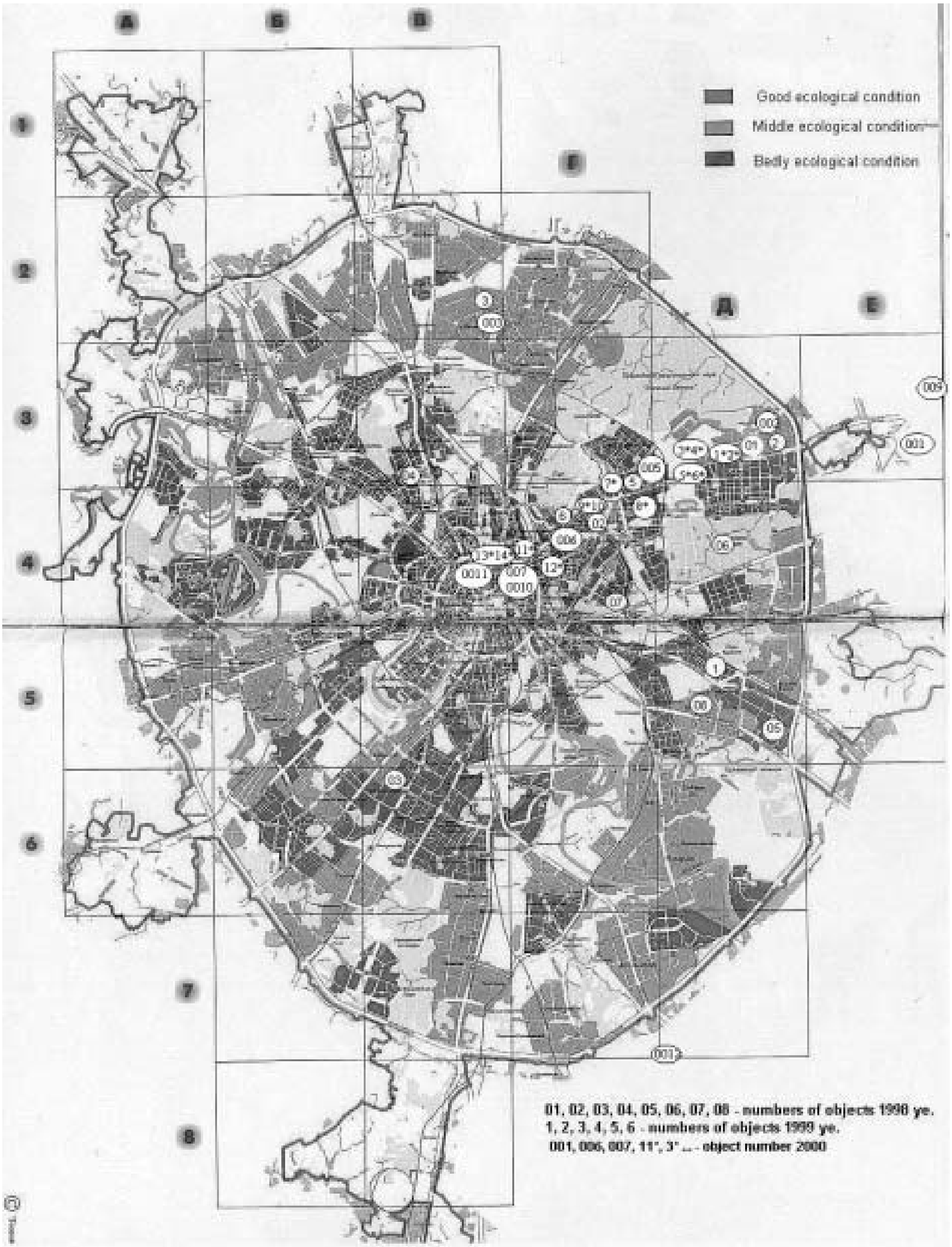

Fig.3. Ecological map of Moscow (Lihachova,1990). The objects of field experiments

That’s why it was decided to use only middleaged leaves.

It is known that the method “of a cutted leaf ” used for years has some shortcomings. The sources of mistakes are varied. For example, some mistakes may occur as the leaf is weighed not in its natural conditions. Some physiological alterations occur in the separated leaf: the stoma width changes. But this method gives good results when plants suffer a lack of water and the transpiration is rather weak (Slatcher, 1970).

Soil was sampled down to the depth where the bulk of roots of small-leaved linden inhabit – on average up to 1 meter. Among water / physical parameters of the soil were studied humidity, aggregate analysis, and density, and among chemical parameters, humus, flexible phosphorus, potassium and metabolic sodium, calcium, magnesium and some micro-elements. The analysis was conducted in the soil laboratory at MGUL (Moscow State Forestry University) Chair of Soil Studies, in the V. V. Dokuchaev Soil Institute, and at theWageningen University.

The quantity of trees taken for research and solution of the main issues was 105 pieces, with 140 extra trees. Extra trees were selected where the 105 original trees could not provide enough last shoots or enough leaves for the transpiration measurements. The number of leaves used to determine the area of leaves was 4500 pieces, the number of leaves used to determine transpiration and the leaf drying rate was 300 pieces, the number of the last shoots was 720 pieces. Shoot length is only studied in 2000. Transpiration of a tree was measured by measuring transpiration of 15–35 leaves. The number of leaves that could be handled with the balance at the street locations depended on the wind conditions. Last shoot length of a tree was measured by measuring 10–20 shoots. This large number was needed to obtain sufficient accuracy.

In this investigation work the classification of trees by categories, worked out by Mozolevskaya (1996), was used.

Table 2. Classification of trees by categories, worked out by Mozolevskaya (1996)

№	Tree Status Category
0	no signs of weakening
1	Weakening with less than 25% of leave drying
2	Moderate weakening with 25% - 50% of leave drying
3	Severe weakening with 50% - 75% of leave drying
4	Drying trees with over 75% of leave drying
5	Dead wood of the current year
6	Dead wood of previous years

From the above categories, only No. 1, 2, 3, and 4 were taken for research (Fig. 4, 5, 6, and 7).

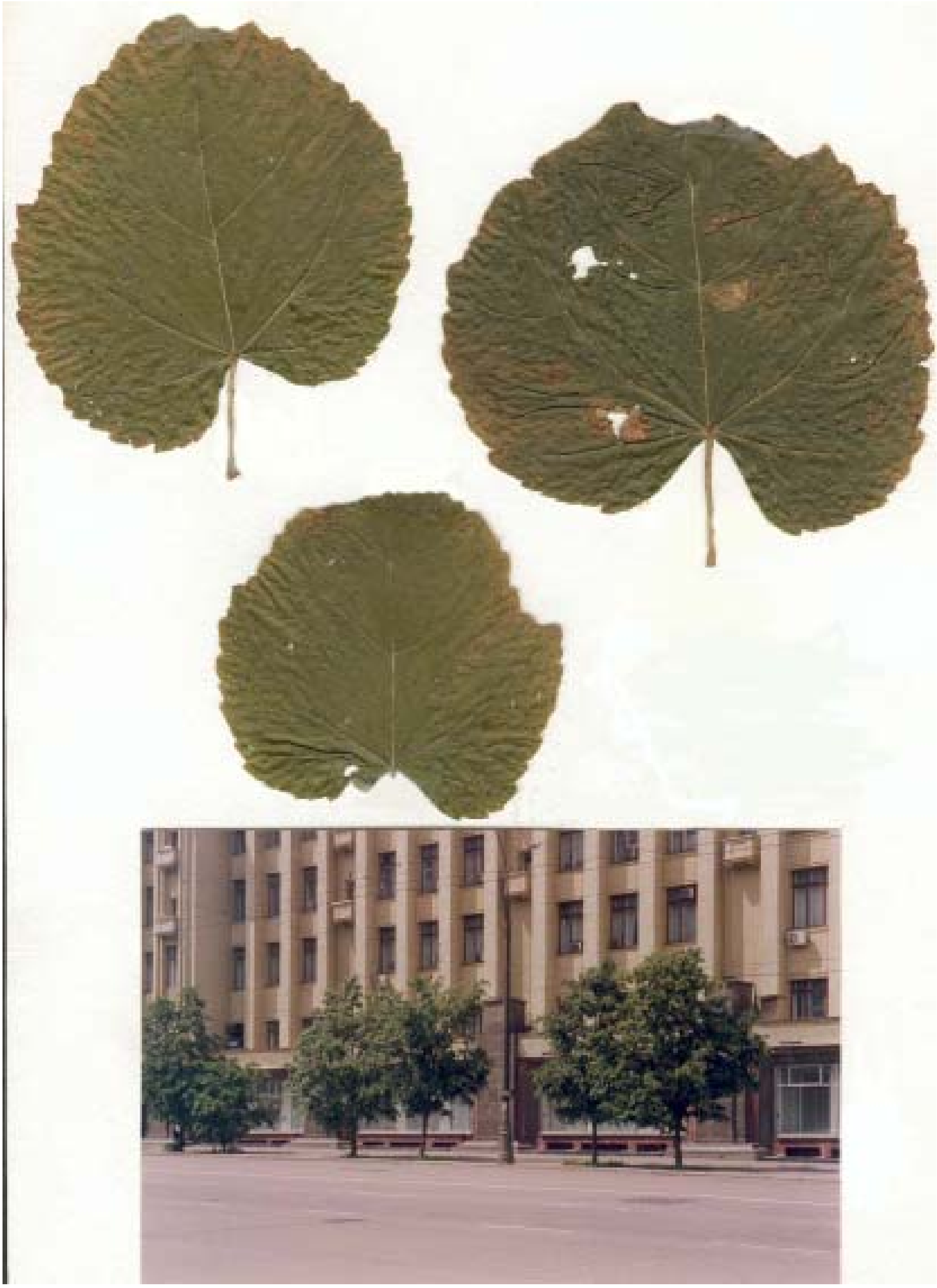

Fig.4. The tree condition with less than 25% of branch drying.

Fig.5. The tree condition with branch weakening that ranges from 25% to 50%.

Fig. 6. The tree condition with branch drying that ranges from 50% to 75%.

Fig. 7. The tree condition with drying trees with over 75% of branch drying.

4. SOIL CONDITION INFLUENCE ON THE TREES OF MOSCOW CITY. INTRODUCTORY REMARKS, RESULTS AND DISCUSSION

4.1. Plant water deficiency.

4.1.1. Introductory remarks on the role of water stress in tree growth.

According to the published data water deficiency is one of the main limiters of the city tree growth as water is the main component of active plant cells (Whitlow and Bassuk, 1987;Vrecenak, 1984; Spomer,1985; Slatcher, 1970; Lindsey and Bassuk, 1991; Kramor, 1987; Molchanov, 1996; Romanov, 1955). So water has great importance in life of trees. It can be illustrated by enumerating of its functions, which can be gathered in four groups (Kramer and Kozdovsky, 1963):

1. Water is a protoplasm element. It totals 80-90% of green (fresh) weight of the actively growing tissue. There is especially much water in the tissues with high physiological activity, for example, in the root tips, stem tops, and there isn't much water in the tissues with low physiological activity.

2. Water takes part in biochemical processes. It is as important reactive substance for photosynthesis as carbon dioxide. It is also one of the important components in the hydrolysis reaction.

3. Water is essential as a solvent. It is a widely spread solvent in which gases, salts and other soluble substances move from cell to cell and from one free organ to another. Water in cell walls and xylem serves as practically a constant solvent.

4. Water serves for turgor preservation. For maintaining of a certain level of turgor some sufficient amount of water is essential. Cell water stock is needable for fulfilling physiological processes and also for conserving of leaves shape and the shape of some other structures with low level of lignification, for stomata opening, for moving of flower petals and some other elements.

In adult plant cells the main part of water is in the central vacuole, which occupies 80-90% of all cell volume. Vacuoles are lifeless formations (somewhat a membrane sack) used as a reservoir, filled with water solutions of nonorganic salts and organic substances which present the products of cell metabolic activity.

In turgescent cells the central vacuole presses the cytoplasm to the cell wall what promote preserving the cell form in soft plant organs, in leaves, for example. If there is a lack of moisture water is drawn off the vacuoles that causes a loss of turgor and violation of main physiological processes in the cell: transpiration, photosynthesis, breathing (Terenkov and Terenkova, 1985; Veretennikov, 1987; Doyarenko, 1966, 1967; Slatcher, 1970). Fig. 8 shows some ways that water lack influences the basic physiological processes of a tree (Kramer., 1963).

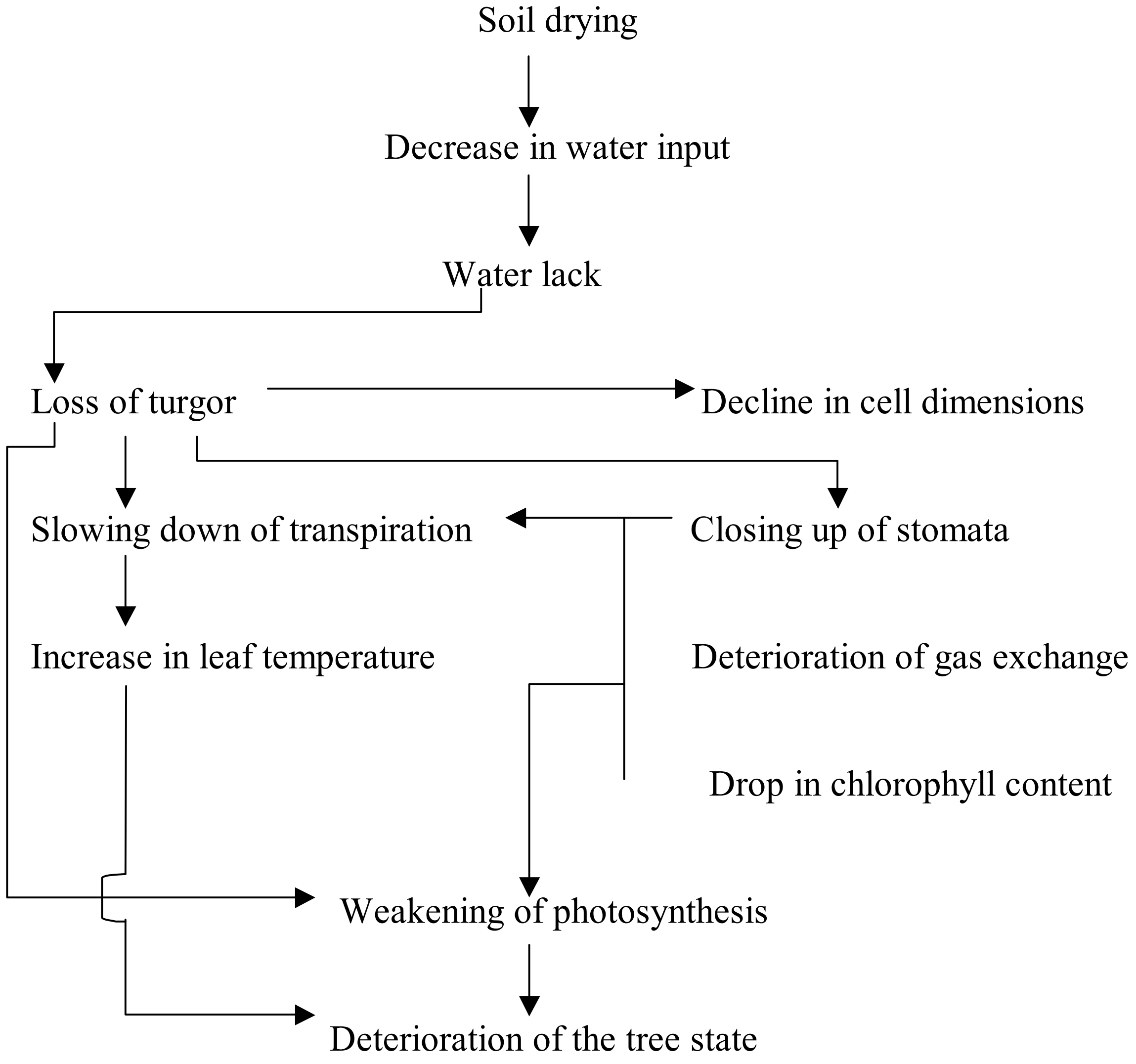

Fig. 8. Water Lack Influence on Some Physiological Processes

In order that the cell could keep the proper life ability the moisture content in its protoplasm shouldn't go out of certain limits. Though the amount of precipitation and soil moisture varies a lot a green plant manages to maintain its waterfulness at a relatively constant level. It is attained by the reduction of transpiration by means of stoma closing. Stoma closing is considered to be a sensitive indicator of violation of inner plant water balance. In the conditions of severe drought the stomata will be closed the most part of the day, the transpiration will be reduced to the size of cuticular transpiration. That will cause a significant leaf temperature heightening. Even little withering causes leaf temperature heightening by 6^{o} C and more. In the dry country conditions stoma closing as a result of inner water deficit can be useful. But in the conditions of our zone it is detrimental as it causes undesirable consequences: gas interchange between atmosphere and inner area of the leaf is violated which reduces the photosynthesis efficiency. In the conditions of severe water deficit photosynthesis will fall down up to the indices close to 0 because of the delay of carbon dioxide incoming and because the level of waterfullness effect photosynthetic reactions (Kushnirenko, 1984).

As the majority of metabolic processes slows down, the intensity of breathing is sure to lower. It is clear, as the relative value of the breathing rate (even if the last remains constant) heightens quickly, when the photosynthesis lowers because of water deficiency. Breathing is the process by means of which the nutrients, generated by photosynthesis, oxidize with detachment of energy and carbonic acid. As all structure elements and all organic components of protoplasm consist of carbohydrates and their derivatives, the lessening of the carbohydrate stock (as a result of excessive expenditure while breathing) can expose the plant to danger. It is well-known that the plants grown in the conditions of lack of water differ from the plants grown in the abundance of water. For example, a lack of water causes for all plants transformation of starch into sugars, conversion of nitrogen exchange in plants. A lack of water also changes the balance between protein synthesis and its hydrolysis for the benefit of the last. In the drought-resisting plants when the drought is mild the process of protein synthesis prevails over its hydrolysis. When the lack of water becomes rather severe, the protein synthesis stops absolutely and the protein destruction causes accelerated migration of nitrogen and phosphorus combinations from laminae into stem. The protein decay causes the appearance of ammonia, which in its turn causes the leaf necrosis. In the drought-resisting plants these processes go slower. If the drying goes on, the cell fission and growth also cease. At the same time the constant loss of the dry weight (expended for breathing) leads to the negative values of total growth. At last, the level of protoplasm dehydration comes up to the critical point (death point) and some cells and materials die. As a rule, if the drought comes slowly, old leaves first die, and if it falls suddenly, the young leaves with low water potential will be the first to die.

The water deficiency affects the processes of absorption and penetration, air and solutions motion, anatomic and physiological root characteristics. In favourable soil conditions a well-ramified viable root system develops. For example, pine in favourable conditions forms deep and strong rootage, whose pivotal root can reach 2-3 m in depth. In usual conditions elm has shallow rootage as well as juniper, maple rootage has one pivotal root, which penetrates up to 1 m deep, and a number of branch roots, spread far aside. In the city soil environment tree root systems are significantly modified. For example, the roots of trees in the street soil environment expand through the spots of loose humus soil and change their forms (deform) on meeting debris, weaken and die. In case if the planting hole is evenly filled with humus, the lime rootage expands in the layer up to 30-50 cm. The roots of the trees planted into a lawn (of small leaved lime-trees, for example) have more favourable conditions than the roots of the trees planted in shallow holes amidst asphalt. Because of debris the roots mainly expand in upper layer. The roots of a small leaved lime planted in line in a strip lawn expand by 2-2,5 m aside and up to 1 m deep. Some separate roots expand by 3,5 m. In the park environment its roots expand by 5,6-6 m from the stem and up to 1,7-2 m deep. In the forest environment the lime roots move aside from the stem by 7-9 and more metres. When the trees are planted in shallow holes the roots don't limit themselves to this small volume. While expanding in the surface layer (0-20 cm deep) some separate roots move far under asphalt (sometimes up to the middle part of the carriage-way). But they branch out weakly and usually don't move deeper than 15-20 cm. On the whole the roots expand within the planting hole. Some separate roots expand no more than 1 m deep.

4.1.2. Transpiration and leaf drying as a diagnostic characteristic.

It is known that the plant water regime is the whole complex of water income and expenditure processes (water adsorption, conduction through the plant, transpiration, assimilation by cells). As 90…95% of the consumed water is expended on evaporation the transpiration indices may be used as a diagnostic characteristic of the plant available water supply in the vegetation period.

Special interest is excited by definition of the water amount necessary for forming of dry and green substance, which is named a transpiration rate or transpiration coefficient. The transpiration coefficient of the majority of plants fluctuates from 200 to 1000. For example, elm has the coefficient equal in the average to 230, palm – 300, birch – 320, oak – 350. The transpiration rate index is quite variable. It depends on the season, on the complex of soil, ecological and meteorological factors. The leaves of the upper layers of woody plants as a rule vaporise more intensively than of the middle and bottom ones. It is known that the water regime of the plants becomes more intense when blossoms and fruit occur. That's why it is so essential to maintain the optimal moistening of the soil in the period of blossoming and fruiting.

A transpiration rate was defined in the period of fruiting of small leaved lime with the use of a torsion balance (Skazkin et al., 1958).

When determining the transpiration of the cut leaves all the weight changes were registered every short stretch of time (2-4 min). Observations were held within 20…25

min after the leaves had been cut as further under the absence of water compensation the leaf begins to fade. The cut leaf was weighted every 2-4 min by a torsion balance (Table 3).

Table 3 Example of Fresh and oven-dry Leaf Weight during Observation Period. Part of original data sheet showing data from a part (9) of the measured leaves from a tree of item 6, 2000

Leaf Area, cm2	**Dry leaf weight, mg**	**Fresh Leave Weight during Observation Period (hrs), mg**									
		9,45	**9,48**	**9,51**	**9,54**	**9,57**	**10,00**	**10,03**	**10,06**	**10,09**	**10,12**
42,07	181	624	617	610	599	593	589	583	578	569	563
55,69	195	703	695	684	678	671	653	649	642	631	624
52,24	210	710	701	692	685	679	670	661	652	645	631
54,14	290	932	925	917	910	897	885	874	865	854	843
		Fresh Leave Weight during Observation Period (hrs), mg									
		10,20	**10,23**	**10,26**	**10,29**	**10,32**	**10,35**	**10,38**	**10,41**	**10,44**	**10,47**
35,17	168	647	633	625	618	611	604	597	589	581	574
73,97	270	885	877	869	861	853	845	837	829	820	825
69,48	282	907	895	887	880	874	867	859	851	843	835
53,45	246	811	804	769	789	781	774	767	760	754	747
31,55	196	712	710	703	694	689	684	679	671	664	658

Further a transpiration rate or intensity (data series showing decrease of water content with time) was defined by the formula: ((fresh leave weight – dry leave weight)/dry leave weight) · 100. An example of transpiration intensity is given in Table 4.

Table 4 Transpiration Intensity (data series showing decrease of water content with time) for Small-Leaved Linden in the City.(example of item 6, 2000)

Leaf Area, cm2	**Dry leaf weight, mg**	**Water content change during Observation (hrs), %**									
		9,45	**9,48**	**9,51**	**9,54**	**9,57**	**10,00**	**10,03**	**10,06**	**10,09**	**10,12**
42,07	181	244,75	240,88	237,02	230,94	227,62	225,41	222,10	219,34	214,36	211,05
55,69	195	260,51	256,41	250,77	247,69	244,10	234,87	232,82	229,23	223,59	220,00
52,24	210	238,10	233,81	229,52	226,19	223,33	219,05	214,76	210,48	207,14	200,48
54,14	290	221,38	218,97	216,21	213,79	209,31	205,17	201,38	198,28	194,48	190,69
		Water content change during Observation (hrs), %									
		10,20	**10,23**	**10,26**	**10,29**	**10,32**	**10,35**	**10,38**	**10,41**	**10,44**	**10,47**
35,17	168	285,12	276,79	272,02	267,86	263,69	259,52	255,36	250,60	245,83	241,67
73,97	270	227,78	224,81	221,85	218,89	215,93	212,96	210,00	207,04	203,70	202,56
69,48	282	221,63	217,38	214,54	212,06	209,93	207,45	204,61	201,77	198,94	196,10
53,45	246	229,67	226,83	222,60	220,73	217,48	214,63	211,79	208,94	206,50	203,66
31,55	196	263,27	262,24	258,67	254,08	251,53	248,98	246,43	242,35	238,78	235,71

Just after the cutting of the leaf a short-term intensification accompanied with dilatation of the stoma slit is to be observed. At that moment the transpiration can increase by 10-20% and then lower again after the water content has fallen down and the degree of the stoma opening has decreased. It should be taken into consideration while using this investigation method. (Slatcher, 1970.).

Therefore, we cannot take into consideration the transpiration value obtained immediately after leaf cutting, as in this case transpiration will not conform to such state of the leaf water saturation as the leaf had when on the plant.

In this connection, the transpiration computed by using this method is at the base of the water loss between the initial value (just after the cutting) and the one obtained 15 minutes later after the cutting.

The data on transpiration intensity of all examined trees at different urban facilities is given in Table 5. The transpiration intensity in this Table is calculated as the water loss in mg during 15 minutes after leaf cutting divided by the leaf dry weight in g. In this Table, confidence interval is the range of values of the individual leaves, and experience error = (mean of deviations from mean value/mean value)*100 %.

Table 5. Transpiration Intensity of Small-Leaved Linden
At Different Urban Facilities

Year	Location of the Facility	Tree State	Average Transpiration Intensity, mg/g of dry weight	Confidence Interval	Experience error,%
2000	Forest Clearing	W/o drying	**155,62**	15,15	10,0
	Square	<25%	188,59	15,67	8,3
	City center		199,77	20,77	10,4
	City suburb		169,99	16,18	9,5
	Mid-town		234,46	21,96	9,4
	Average value		**198,20**		
	City center	25-50%	194,57	18,84	9,7
	City center		218,27	9,93	4,5
	Average value		**206,42**		
	Mid-town	50 - 75%	186,90	15,98	8,6
	City suburb		182,61	11,13	6,1
	Average value		**184,76**		
1999	Square	<25%	204,05	23,29	11,4
	City center		196,51	25,61	13
	Average value		**200,28**		
	City suburb	25-50%	**238,64**	24,7	10,3
	Square	50 - 75%	147,5	9,5	6,4
	City suburb		175,76	18,77	11
	City suburb		166,34	14,83	8,9
	Mid-town		176,82	17,39	9,8
	City center		127,09	11,33	8,9
	Average value		**158,702**		

From Table 5 it is clear that the transpiration rate of the small-leaved lime growing both in the city environment and in the forest clearing conditions is quite low. Unfortunately, though the selection of objects for the investigation was quite severe the obtained data don't display clear dependence of the transpiration rate on the state of the tree. It can be caused by different reasons. For one thing, for the definition of transpiration the weighing method was used, which has rather a high error in indication. For another thing, the obtained indices have rather low values. According to multiple research, a plant needs 300-800 times as much moisture as the dry plant weights at harvest. According to the published data the small-leaved lime by the transpiration rate belongs to high-transpiring species (Veretennikov, 1987.). The transpiration rate of the small leaved lime is equal to 400-500 mg/g of the fresh weight per hour and more. Table 5 shows values of 127,09-238,64 mg/g of leaf dry weight per 15 minutes. Such low indices of the transpiration rate obtained in the studies (on the trials) could be only caused by the tree water stress.

It was attempted to find more interesting dependencies by extending the time period of measurements. So, not basing on the method in which the leaf transpiration rate is calculated for the 15 minutes period after leaf cutting, but on the water loss rate registered during a few hours period after the cutting. For that purpose the fresh cut leaf was weighed every hour. The leaf was observed for 6-8 hours. Then on the base of the observed data transpiration and drying rates were calculated. Rate of the leaf drying was expressed in 2 different ways, using the following different rates of water content change:

1. (The initial leaf water content – the leaf water content “n”* hours later after the cutting)/n;

2. (The leaf water content at the previous sampling point – the leaf water content at the considered sampling point)/time interval between sampling points.

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* “n” – the time passed after the cutting .

The difference between these formulas is that in the first formula, a value of the leaf water content (one of those, which were obtained every hour) is subtracted from the initial value. In the second one a subsequent value of the leaf water content is subtracted from the previous one. For example, the value obtained an hour later is subtracted from the initial one, the value obtained two hours later is subtracted from the second value, the value obtained three hours later is subtracted from the third one and so on. Calculation examples are given in Tables 6, 7, 8 and 9.

Table 6. Weight of freshly cut leaves, hour by hour of observation, mg (part (9) of the sampled leaves from a tree from item 6, 2000)

Leaf area, cm2	Dry leaf weight, mg	Weight of freshly cut leaves, hour by hour of observation, mg									
		9,45	**11,00**	**12,00**	**13,00**	**14,00**	**15,00**	**16,00**	**17,00**	**18,00**	**19,00**
42,07	181	624	497	464	432	412	390	365	334	315	303
55,69	195	703	589	561	546	524	484	458	430	410	388
52,24	210	710	599	573	554	520	475	454	409	382	368
54,14	290	932	802	773	734	657	582	526	479	431	394
		10,20	**11,20**	**12,20**	**13,20**	**14,20**	**15,20**	**16,20**	**17,20**	**18,20**	**19,20**
35,17	168	647	532	499	464	433	402	345	316	280	266
73,97	270	885	791	762	721	690	647	594	528	522	502
69,48	282	907	803	784	753	699	648	594	540	505	480
53,45	246	811	705	677	640	580	533	487	443	408	384
31,55	196	712	615	589	558	460	390	328	286	259	240

Table 7. Leaf drying rate calculated as a series of water contents: (((weight of fresh leaf – weight of oven-dry leaf)/ weight of absolutely dry leaf) * 100) at a series of points in time (item 6, 2000)

Leaf area, cm2	Dry leaf weight, mg	Leaf drying rate (water contents (%) at a series of points in time)									
		9,45	**11,00**	**12,00**	**13,00**	**14,00**	**15,00**	**16,00**	**17,00**	**18,00**	**19,00**
42,07	181	244,75	174,59	156,35	138,67	127,62	115,47	101,66	84,53	74,03	67,40
55,69	195	260,51	202,05	187,69	180,00	168,72	148,21	134,87	120,51	110,26	98,97
52,24	210	238,10	185,24	172,86	163,81	147,62	126,19	116,19	94,76	81,90	75,24
54,14	290	221,38	176,55	166,55	153,10	126,55	100,69	81,38	65,17	48,62	35,86
		10,20	**11,20**	**12,20**	**13,20**	**14,20**	**15,20**	**16,20**	**17,20**	**18,20**	**19,20**
35,17	168	285,12	216,67	197,02	176,19	157,74	139,29	105,36	88,10	66,67	58,33
73,97	270	227,78	192,96	182,22	167,04	155,56	139,63	120,00	95,56	93,33	85,93
69,48	282	221,63	184,75	178,01	167,02	147,87	129,79	110,64	91,49	79,08	70,21
53,45	246	229,67	186,59	175,20	160,16	135,77	116,67	97,97	80,08	65,85	56,10
31,55	196	263,27	213,78	200,51	184,69	134,69	98,98	67,35	45,92	32,14	22,45

Table 8. Leaf Drying Rate: series of rate of water content changes (% min^{-1}) between subsequent points in time (item 6, 2000)

Leaf area, cm2	**Dry leaf weight, mg**	**Leaf Drying Rate, % min^{-1}**									
		9,45	**11,00**	**12,00**	**13,00**	**14,00**	**15,00**	**16,00**	**17,00**	**18,00**	**19,00**
42,07	181		0,94	0,30	0,29	0,18	0,20	0,23	0,29	0,17	0,11
55,69	195		0,78	0,24	0,13	0,19	0,34	0,22	0,24	0,17	0,19
52,24	210		0,70	0,21	0,15	0,27	0,36	0,17	0,36	0,21	0,11
54,14	290		0,60	0,17	0,22	0,44	0,43	0,32	0,27	0,28	0,21
		10,20	**11,20**	**12,20**	**13,20**	**14,20**	**15,20**	**16,20**	**17,20**	**18,20**	**19,20**
35,17	168		1,14	0,33	0,35	0,31	0,31	0,57	0,29	0,36	0,14
73,97	270		0,58	0,18	0,25	0,19	0,27	0,33	0,41	0,04	0,12
69,48	282		0,61	0,11	0,18	0,32	0,30	0,32	0,32	0,21	0,15
53,45	246		0,72	0,19	0,25	0,41	0,32	0,31	0,30	0,24	0,16
31,55	196		0,82	0,22	0,26	0,83	0,60	0,53	0,36	0,23	0,16

Table 9. Leaf Drying Rate: series of rate of water content changes (% min^{-1}) between time of leaf cutting and a series of points in time (item 6, 2000)

Leaf area, cm2	**Absolutely dry leaf weight, mg**	**Leaf drying rate, % min^{-1}**									
		9,45	**11,0 0**	**12,00**	**13,00**	**14,00**	**15,00**	**16,00**	**17,00**	**18,00**	**19,00**
42,07	181		0,94	0,65	0,54	0,46	0,41	0,38	0,37	0,34	0,32
55,69	195		0,78	0,54	0,41	0,36	0,36	0,34	0,32	0,30	0,29
52,24	210		0,70	0,48	0,38	0,35	0,36	0,33	0,33	0,32	0,29
54,14	290		0,60	0,41	0,35	0,37	0,38	0,37	0,36	0,35	0,33
		10,20	**11,20**	**12,20**	**13,20**	**14,20**	**15,20**	**16,20**	**17,20**	**18,20**	**19,20**
35,17	168		1,14	0,73	0,61	0,53	0,49	0,50	0,47	0,46	0,42
73,97	270		0,58	0,38	0,34	0,30	0,29	0,30	0,31	0,28	0,26
69,48	282		0,61	0,36	0,30	0,31	0,31	0,31	0,31	0,30	0,28
53,45	246		0,72	0,45	0,39	0,39	0,38	0,37	0,36	0,34	0,32
31,55	196		0,82	0,52	0,44	0,54	0,55	0,54	0,52	0,48	0,45

Practically all observations were held in the city environment on the pavement along highways (except two objects which were situated in a public garden and in the forest near Moscow). A great number of leaves were weighed in consecutive order. 5-8 species were cut and weighed straight away. It took only 1-2 min. Every leaf had its own number and the time of measuring was fixed. Measures were repeated 4 times. Unfortunately, it was impossible to repeat it more frequently as in this case one more factor – time – began to effect the transpiration rate. All the observations were held only in morning time – from 9.30 to 11.00. Further investigations in leaf drying were held in laboratory conditions. In most cases 20-35 leaves from each tree were examined in the course of investigations.

As the amount of leaves was large, the weighing was held in complicated field conditions and the distances between the objects and the laboratory were different it was impossible to fulfil measures in unified time system. Some leaves were weighed strictly an hour later, others – 1.05 and 1.15 hours later. That's why each series of leaf drying values was transformed into a curve (continuous function of time) using a curve – fitting technique. This approximation made it possible to compare and process all the data at the same time steps. The example of obtained data is given in Table 10.

Table 10. Example of leaf drying rate on the basis of actual and approximated data (item 6, 2000): based on (water content at the initial measurement – water content at the given observation time after the initial measurement)/observation period

Actual observation period, min.	**Leaf drying rate, % min-1**	**Approximated period, min.**	**Approximated leaf drying rate, % min-1**
102	0,75	60	0,80
162	0,23	80	0,63
222	0,20	120	0,46
282	0,27	140	0,41
342	0,33	160	0,37
402	0,24	180	0,35
462	0,29	200	0,33
522	0,21	220	0,32
582	0,16	240	0,30
		300	0,27
		350	0,26

4.1.3. The urban tree condition and leaf drying rate.

As a result of research, rather interesting data were obtained. All approximated values of leave drying rate of small-leaved linden with different state are given in Figures 9, 10, 11, 12, 13, 14, 15, 16.

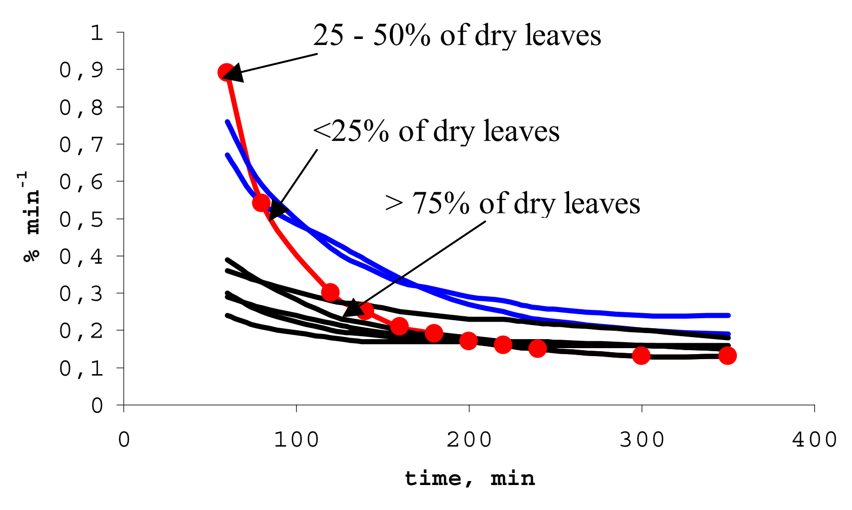

Fig. 9. Leaf drying rate calculated as series of: (water content at the initial measurement point – water content at the considered point in time)/time between both points. 1999 data (individual trees).

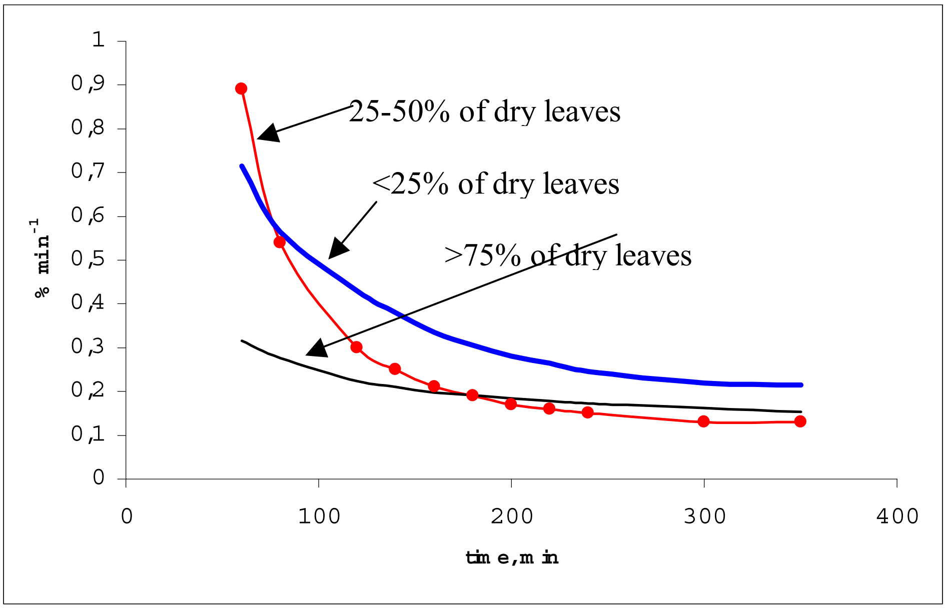

Fig 10. Leaf drying rate calculated as series of: (water content at the initial measurement point – water content at the considered point in time)/time between both points. 1999 data (on average).

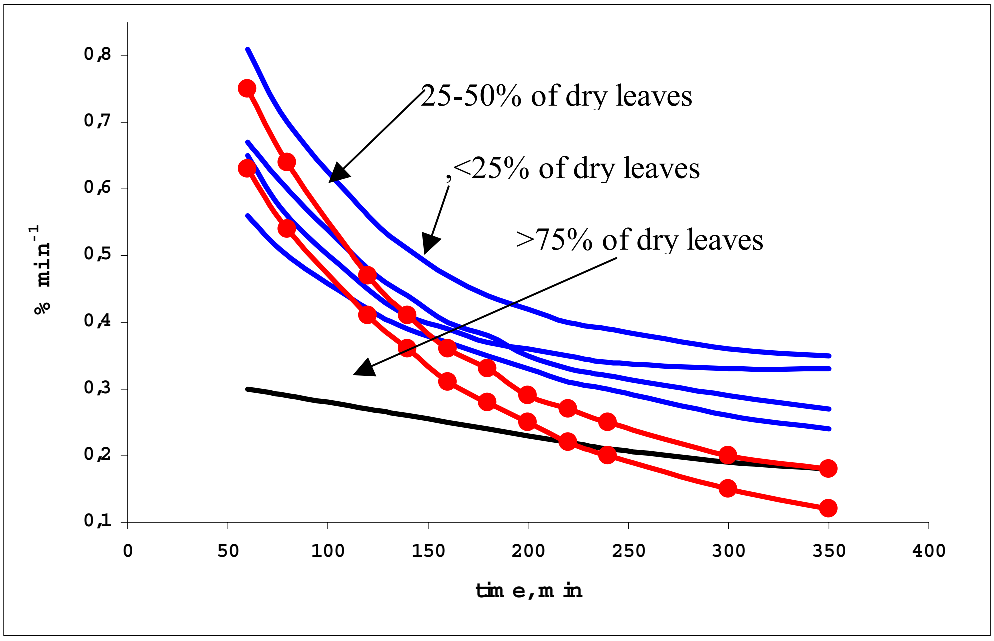

Fig. 11. Leaf drying rate calculated as series of: (water content at the initial point – water content at the considered point in time)/ time between both points. 2000 data (without control, individual trees).

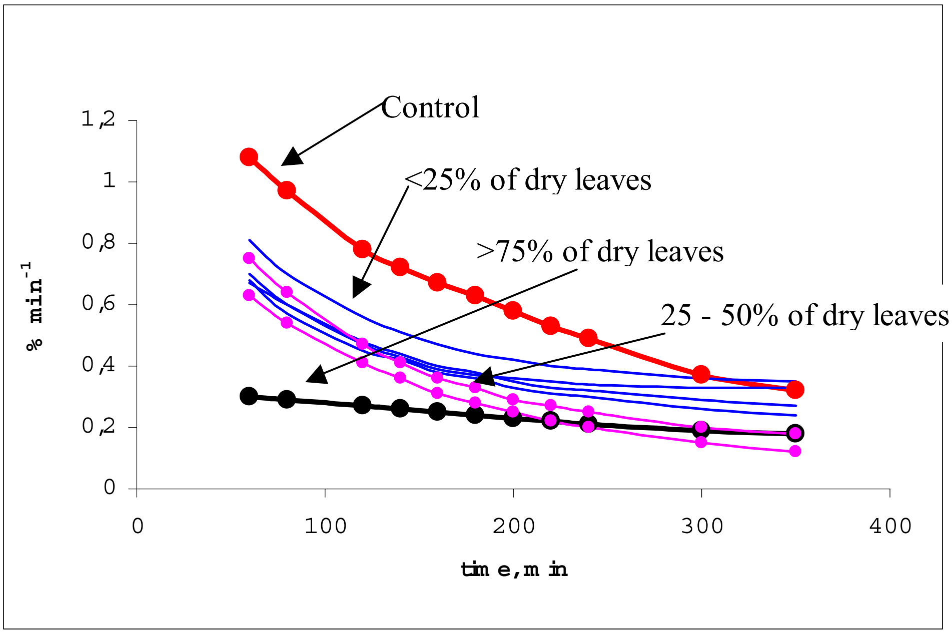

Fig. 12. Leaf drying rate calculated as series of: (water content at the initial measurement point – water content at the considered point in time)/time between both points. 2000 data (with control, individual trees).

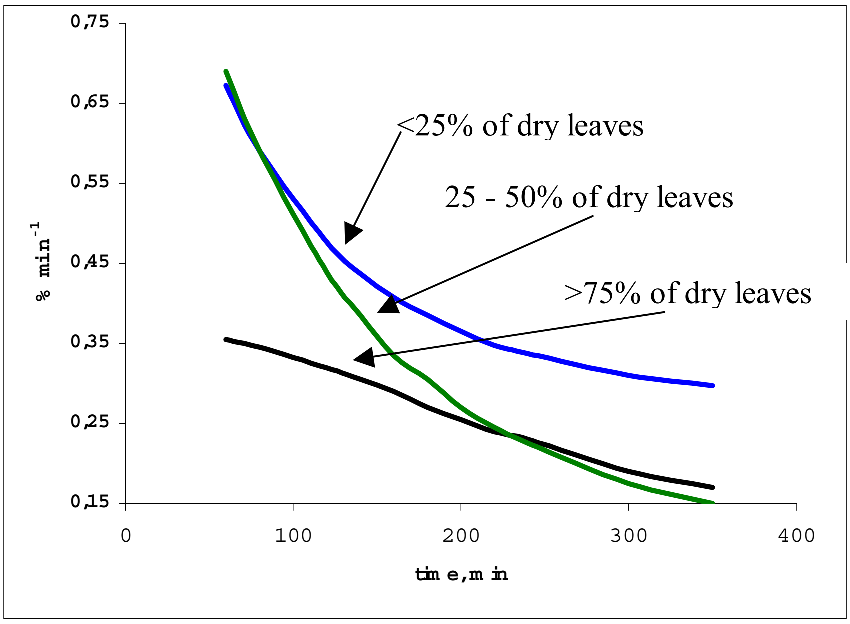

Fig. 13. Leaf drying rate calculated as series of: (water content at the initial measurement point – water content at the considered point in time) / time between both points. 2000 data. (without control, on average).

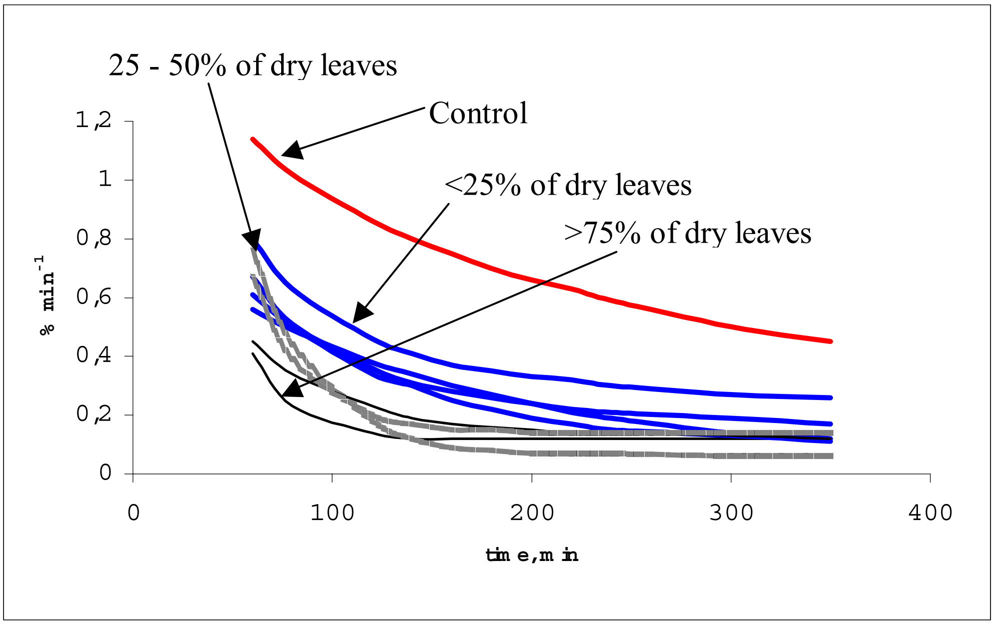

Fig. 14. Leaf drying rate calculated as series of: (water content at the previous considered point in time – water content in the considered point in time) / time between both points. 2000 data. (with control, individual trees).

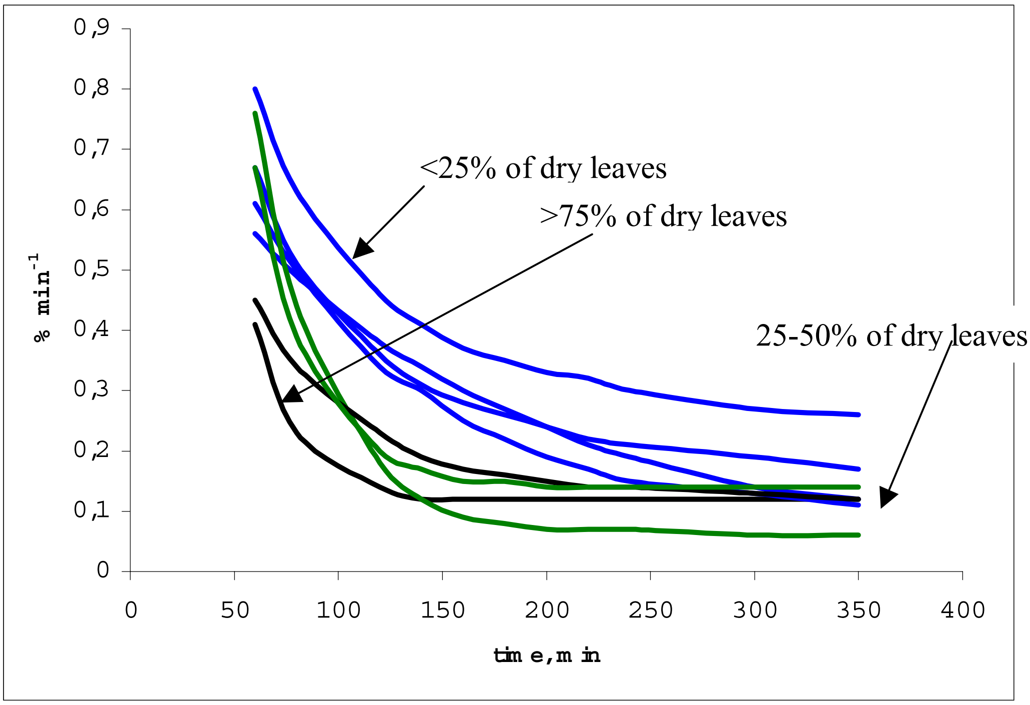

Fig. 15. Leaf drying rate calculated as series of: (water content at the previous considered point in time – water content at the considered point oin time) / time between both points. 2000 data (without control, individual trees).

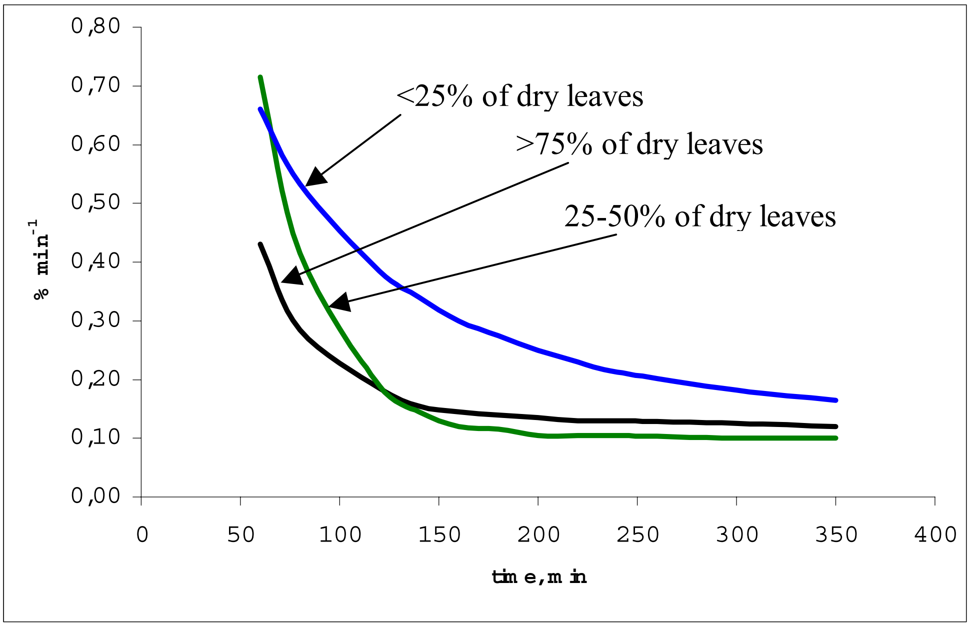

Fig. 16. Leaf drying rate calculated as series of: (water content at the previous considered point in time – water content at the considered point in time) / time between both points. 2000 data (without control, on average).

The observed data indicate that the leaves of the trees with different status have different leaf drying rate. A tree in ecologically favourable conditions (in a forest clearing) keeps the highest amount of water in the cells, and in 5-6 hours after cutting, the leaf of this tree retains the maximum moisture content. In the city environment, i.e. in more difficult environmental conditions, practically all the investigated trees suffered water stress and it affected the tree status and the rate of leaf drying. The stronger the water stress the worse the tree status.

The trees with the leaf drying indices equal to >75% have the largest water deficit in comparison to the trees with better status. The amount of water in the leaves of these trees just after cutting is minimum. And the leaf drying rate of these trees is accordingly minimum.

The trees with the leaf drying indices equal to <25% have in comparison to other city plants the highest moisture content indices at the initial observation time and 5-6 hours later after leaf cutting. Though their indices are much lower than those of the trees growing in their natural soil environment in the forest clearing.

The trees with the leaf drying indices equal to 25-50% have an intermediate position. On the one hand, they contain quite a large amount of moisture in the leaves just at the moment of cutting. The moisture amount in this case is comparable to the moisture amount in the leaves of the city trees of the best status. On the other hand, 5-6 hours later the amount of moisture in the trees approximates to the indices of the trees with rather a poor status.

Figs 9-16 present relationships that are measured in an unambiguous quantitative way. It is generally felt that quantitative methods are to be preferred above visual methods that need expertise and are subjective to a certain extent.

4.2. Physical parameters of soil and water deficit of the plants.

4.2.1. Introductory remarks on soil humidity.

Thus it can be supposed that the water deficit causing significant changes of the majority of physiological processes seriously affect the water content in the leaves and the ability to preserve moisture in the leaves for a long time after cutting.

Inner water deficit of the plants can be caused by the following factors (Wager, 1986; Whitlow and Bassuk, 1987, 1998; Spomer, 1985; Vrecenak, 1984; Slatcher, 1970; Kramor, 1987):

1) straight sun rays;
2) heightened city air temperature;
3) low relative ambient humidity;
4) heightened temperature of the sub-black soil;
5) strength of wind;

6) the soil conditions.

A typical plant, fairly provided with water and nutrients, with the normal level of transpiration suffers a lack of water only a little in summer in the afternoon. It doesn't practically effect the growth of the plant as the water deficit is not severe or long. Usually the water deficit caused by heightened transpiration rate at high tense of meteorological factors by day-time wears off in the evening and at night, when the transpiration process becomes weak.

But in some cases, especially at a lack of water in the soil, the plant doesn't manage to defray the water expenses of the day-time and by the sunrise there is some lack of water in the leaf tissue. This water deficit is named residual. The residual water deficit can be observed at dawn and indicates that the leaf water stock is restored only partially because of low level of the soil humidity. As this takes place the plant first fades and then dies under the conditions of further long drought.

If the drought gains strength and the water potential approximates to the humidity value of firm fading, the water deficit of the day time will be less essential. The soil water potential will be much more essential than the inner water deficit. The turgor pressure approximates to zero. Thus at low water stocks the water deficit doesn't disappear by night and the residual water deficit is observed. And every next day will begin with the inner water deficit, which will heighten till the soil water saturation has been restored. A lack of soil moisture is most detrimental for the plant vital functions (Goncharick, 1962).

For example, the investigations by Molchanov et al. (1996) indicated that the increase of the lack of water in the soil causes the lessening of the physiological activity of the oak: photosynthesis, transpiration and root breathing loose their activity. Transpiration sharply decreases at the soil drying up to 1 Mpa (water potential). If the water potential (WP) is lower than 2,3 Mpa, roots practically stop carbon-acid gas liberation. If the WP of the soil is equal to 2 Mpa and the air and soil temperature is high, the intensity of photosynthesis lowers by 80%. Beyond 3 Mpa photosynthesis ceases. More considerable water deficit causes predominance of breathing over photosynthesis of the overground part of the oak seedling in daytime and results in negative balance of the organic substance. Even after watering the photosynthesis is restored only by the third day. At the same time the root breathing heightens immediately after the watering. At increasing lack of water in the soil meteoconditions impact photosynthesis and transpiration differently. In the cloudless weather conditions with a lack of soil humidity the day transpiration rate is considerably lower in comparison to the cloudy weather conditions. At the same conditions the root breathing practically doesn't change. Under the conditions of high water deficit in the soil, photosynthesis and transpiration can be observed only early in the morning, and root breathing can be registered only by day time .

There is some interdependence between the soil humidity and transpiration. At the WP (water potential) of 80% there is the largest sum plant transpiration. Also the soil humidity impacts the day dynamics of transpiration. So when WP is 80% maximum day transpiration is observed from 12 to 3 PM, when WP is 70% there are two maxima (since 9 to 11 AM and since 1 to 2 PM).The soil humidity decreases up to 69% WP used to cause the decreasing of the transpiration rate and shifting of the day peaks to the period from 10 to 11 … to 5 PM. Further decreasing of humidity (up to 40% WP) promoted shifting of the day transpiration maximum to an earlier period (9-10 o'clock) and sharp reduction of water expense on the transpiration (Giyayeva et al., 1984).

Plant water supply under different indices of humidity and other equal conditions is carried out with different intensity. At small water stock level the water holding force increases and makes the water access from the roots to the leaves difficult. This doesn't permit to indemnify completely the day water deficit in the plants' tissue. Exceeding of the water expense over its supply causes the water balance violation and formation of the plant water deficit. Its presence in the plant tissue within some limits and in certain day time is a natural phenomenon. But its presence during daylight hours and by night (at the values critical or about it) causes the violence of physiological processes and lowering of the plant productivity. At the presence of high moisture stocks approximate to the minimum of the field water holding capacity the water deficit occurring during the day hours vanish during the night hours. If the water stocks are small, the water deficit doesn’t vanish by night and the plant suffers a lack of water and a residual plant water deficit is observed (Litvinov, 1951). So every other day will begin with insignificant inner water deficit, which will grow until the soil water reservoir has been replenished (Clark and Kjelgren, 1990).

The strike root rate of newly planted trees depends on the amount of available moisture. Thus in Seattle the strike root rate approximates 100% if the trees have been watered for 2 years. Large trees which are deprived of additional watering will be able to sustain the conditions of an unusually hot year better than the trees which have been watered regularly, as in this last case the consumption of water by trees is balanced by the amount of the available moisture at this area. If this amount suddenly decreases, the tree has to accommodate itself to these new conditions and to restore the balance between its productivity and the environmental conditions. It will take several years. If the amount of available water decreases considerably and the tree suffers an acute stress, it can loose its liveliness and even die. Any drought may be catastrophic for the trees which have had additional watering for many years before the drought (Clark and Kjelgren, 1990).

The investigation data by Kochanovsky (1964) indicate that under the limes with normal status the soil humidity is 1,5-2 times higher than under the limes with the leaves prematurely turning yellow. The author also determined that the soil humidity in the layer up to 60 cm under the trees in a decorative grass-plot is 1,5-2 times higher than under the trees planted amidst asphalt.

Soil moisture plays a decisive role in plant life, it is a life basis. For normal life support, there is need in permanent and sufficient moisture content in soil.

As is well known, plants need a certain water quantity to create a unit of dry matter content. As there is relationship between plant transpiration and moisture content in soil, transpiration rate can serve as a certain diagnostic feature of a plant's provision with moisture.

Numerous facts prove that transpiration rate weakens on many soils subject to drying.

Side by side with soil drying, stomata of plants start to close increasingly earlier and, as a result, transpiration weakens progressively. However, there is an opinion that a low level of soil humidity produces a fairly insignificant influence on transpiration. This can be explained by the fact that transpiration represents a passive process that regulates air drying capacity and water movement rate in soil to roots. Therefore, low soil humidity mostly influences growth and development of the entire plant rather than only transpiration, in the opinion of many authors.

4.2.2. Soil humidity and tree condition.

Soil humidity was studied under trees with different state during the research period. The findings are shown in Table 11.

Table 11. Urban Soil Humidity under Trees with Different State

Research year	Tree State, Top Drying Percentage	Sampling depth, cm	Average Soil Humidity, %	Experience error,%
1999	<25%	0 - 40	10,63	2,2
	25 –50%	0 - 40	6,30	4,4
	50 -75%	0 - 40	6,72	3,8
	>75%	0 - 40	3,13	4,7
	<25%	40 - 110	12,31	3,5
	25 –50%	40 - 110	6,24	3,7
	50 -75%	40 – 110	7,31	2,9
	>75%	40 - 110	5,36	4,1
2000	<25%	0 - 40	11,44	3,5
	25 –50%	0 - 40	9,60	2,9
	50 -75%	0 - 40	5,12	4,2
	>75%	0 - 40	5,00	4,1
	<25%	40 - 110	14,38	2,7
	25 –50%	40 - 110	10,29	3,3
	50 -75%	40 – 110	7,72	1,9
	>75%	40 - 110	5,31	2,0

According to Table 11, the relationship between tree state and moisture content in soil is fairly easily traced. So, soil humidity is the least under trees with a very poor state. Soil humidity under trees with relatively satisfactory state is almost twice as high.

Supposing, that such water and physical soil conditions take shape along highways as there is soil moisture lack during vegetation period for a number of years, then gradual weakening of plants' vital functions may be expected in these circumstances. Slowing down of growth and development of a tree is likely to affect its exterior state.

4.2.3. Soil texture and tree condition.

As is known, the maximum moisture reserve is formed in soil, given the optimal water and physical parameters of the latter. Granulometric composition and structure of soil are one of its most important features. Therefore, to ensure comprehensive study of diagnostics of the urban soil and plant state in parts with the most severe signs of plant weakening, we performed analyses on soil granulometric composition(soil texture).

Russian classification (Soil classification.., 1977) of soil texture has 5 fractions (Table 12).

Table 12. Russian classification of mechanical elements (fractions)

Fraction	**Size, mm**
Stones, mm	> 3
Gravel, mm	3 – 1
Sand, mm:	
coarse	1,0 – 0,5
medium	0,50 – 0,25
small	0,25 – 0,05
Dust, mm:	
coarse	0,05 – 0,01
medium	0,01 – 0,005
small	0,005 – 0,001
Clay, mm	< 0,001

It is very important to know the size of the dust fraction. Podsols have a relatively large dust fraction.

Table 13. Fractions in Podsols (according to: Philatov, 1932)

Horizon	**Fractions, in %**			
	0,01 – 0,005 mm	**0,005–0,001 mm**	**< 0,001 mm**	**Sum**
A_1	19,3	3,2	3,4	25,9
A_2	17,1	3,9	2,2	23,2
B	12,7	4,3	21,1	38,1
C	14,0	3,7	16,9	34,6

Findings of our analysis are given in Table 14.

Table 14. Dust Fraction Content in Soils on Sites with Different State of Urban Trees

Research year	**Tree State, Top Drying Percentage**	**Sampling depth, cm**	**Average particle values, 0,02 – 0,05 mm,%**	**Experience error, %**
1999	<25%	0 – 40	10	3,7
	25 –50%	0 – 40	12	2,9
	50 -75%	0 – 40	16	4,1
	>75%	0 – 40	16	2,6
2000	<25%	0 – 40	8	2,2
	25 –50%	0 – 40	13	3,5
	50 -75%	0 – 40	17	1,3
	>75%	0 – 40	28	1,9

As is shown in Table 14, dust fraction content is higher in soil under trees in a very poor state vs. soil under trees in a better state. For instance, soil under trees with 75% of top drying contains 28% of particles of 0.02-0.05 mm, with 8%-10% of such particles under mildly weakened trees.

Obtained data do not contradict those in the literature. For instance. Strogonova (1997) also notes that the scarcity of herbage under oppressed vegetation off highways and industrial enterprises leads to transformation of the soil surface into dust (Strogonova, 1997).

As is known, dust possesses rather negative water-related and physical properties. For instance, large dust fractions, by their mineralogical composition, are almost the same as that of sand dust, so it has some physical properties of sand: it is not plastic, poorly swells, with low moisture capacity. Medium dust is characterized by increased content of mica that lends the fraction high plasticity and cohesion. Medium dust, being more dispersive, holds moisture better but possesses poor water permeability, is unable of coagulation, does not participate in structure formation and physical / chemical processes taking place in soil. Therefore, soils enriched with the fraction of large and medium dust are easily dispersed, tend to bloating and compression, and are distinguished by low water permeability. Small dust is characterized by a relatively high dispersion, and consists of primary and secondary minerals. In this connection, it possesses a number of properties untypical for larger fractions: it is able to take part in coagulation and structure formation, possesses absorptive capacity, and contains a high concentration of humus substances. However, abundance of thin dust in soils in a free, non-aggregated state, lends soils such unfavorable properties as low water permeability, high amount of unavailable water, high swelling and compression capacity, stickiness, fissuring, and compact structure.

4.2.4. Soil structure and tree condition.

Therefore, it is the structure nature that mostly determines physical properties of soil, its water, air, and thermal regimens, and consequently, living conditions of plants and micro-flora. Structured soil is many times as air and water permeable as dusty soil, has a higher moisture capacity and evaporates less water, has lower specific resistance during its handling, is easier penetrated by plant roots, and has less difficulty in combating drying and erosion in structured soil.

According to the well-known Russian soil scientist N. A. Kachinskiy, “to deny the significance of soil structure means to deny the significance of all physical properties of soil that are intertwined with structure; and soil chemism and biological (including micro-biological) activities in it are closely connected with physical – air, water, and heat - properties. Thus, opponents of soil structure, actually deny the significance of soil fertility, without being aware of that themselves.”(Kachinskiy, 1955).

Therefore, one can state that soil structure is one of the most important soil properties, which determines all other soil parameters and regimes. By preserving soil structure, we ensure a favourable water / air regime of soil and, accordingly, viability of higher plants.

As is known, macro-aggregates of 0.25-7(10) mm, with high porosity (>45%), mechanical durability and water permeability, are the most valuable in agronomical terms. Structured soil is soil containing over 55% (according to some data, 80%) of water stable aggregates of 0.25-7(10) mm. Agronomically valuable structure in soil creates optimal physical properties – such as porosity, durability, water / air/ heat/ pH / micro-biological and nutrient regimes – as well as physical and mechanical properties, e.g. cohesion, specific resistance, crust formation, etc.

Soils consisting of primary particles are called unstructured soils. Mechanical elements lie compactly in unstructured soil, therefore, mostly capillary pores are formed in it. So, water is slowly absorbed in unstructured soils, its bulk may be lost due to surface run-off.

Studies of balanced filtration rate by I. B. Ruvut in aggregates of 1-2 mm made of ordinary black earth clay and in a column of micro-aggregates suggested that soil from pure aggregates of 1-2 mm with density of 1.0 g/cm^2 is able to permeate up to 1,600 mm of precipitation per hour, and from dust less than 1mm per hour. Hence, it is clear that aggregate soil is able to permeate precipitation from shower rains, whereas micro-aggregate soil fails to permeate precipitation even from drizzling rains.

A dense capillary network in the depth of unstructured soil causes significant moisture losses from evaporation. Interesting research on evaporation of suspended moisture from soil was conducted by Abramov et al. (1956). Their findings suggested that liquid moisture movement to dried area is observed during evaporation from macro-structured soil in columns (1-3 mm aggregates), at the same time the dried layer capacity increases. However, it is to note that less than 10% of initial content of suspended moisture was subject to upward movement during evaporation. Available moisture loss accounted for only 14.3% of its initial content. Authors concluded that but a small percentage of movable moisture is able to move in a liquid form in soils with a well-marked macro-structure. Its bulk (over 90% of total content and over 85% of available moisture reserve) is unable to move in a liquid form towards the surface.

Therefore, a steady water stable structure is a valuable reserve that each correct urban greenery business should try to accumulate, as many physical properties (capillarity, water permeability, aeration, etc.) in structured soils will depend on the structure nature to a greater extent than on its granulometric composition.

Findings of aggregate soil analyses on sites with different state of trees are shown in Table 15.

Table 15. Aggregate Soil Analysis on Sites with Different State of Trees

Research year	State of Tree, Top Drying Percentage	Sampling depth, cm	Aggregate Dimensions (in mm) and Their Content (% of air-dry soil weight) / experience error, %		
			0,5 – 0,25	< 0,25	Summary (< 0,5)
1999	<25%	0 – 40	32/2,4	18	50
	25 –50%	0 – 40	38/1,7	16	54
	50 -75%	0 – 40	48/1,5	19	67
	>75%	0 – 40	57/0,9	21	78
2000	<25%	0 – 40	27/2,7	13	40
	25 –50%	0 – 40	34/2,4	15	49
	50 -75%	0 – 40	51/4,0	24	75
	>75%	0 – 40	56/4,1	19	75

Data from Table 15 illustrate dustiness of soils, in particular on sites with trees in a very poor state. For instance, soil under these trees contains over 75% of aggregates of less than 0.5 mm. The picture is slightly better in soils under mildly and moderately weakened trees. The number of aggregates of less than 0.5 mm in these soils is also high, and does not conform to their optimal content.

Soil humidity during observation period, as is obvious from earlier presented results, dropped to fairly low values. It amounts to less than 10%. As is known, part of the total moisture reserve is not available as source of water support of plants. (Doyarenko, 1966). Naturally, humidity may well fall down to this dead reserve in drought. As a result, plants will lack the adequate moisture quantities, despite moisture availability in soil, the latter not being available for plants.

Of great interest is also pF index that is a measure of the soil dryness state. It reflects the soil capacity to hold its water at a given water content and the absorbing power that a plant root has to exert in order to take water up from the soil. The pF as a function of water content is called the soil water characteristic. The essence of this soil characteristic lies in the fact that each soil possesses different capacity to retain water in different humidity conditions. This capacity to retain water increases when humidity decreases.

4.2.5. Water balance.

The pF value of a soil is the logarithm of the water suction (h) in the soil expressed in cm water column (pF = log (h in cm)). The relationship between pF and the volumetric water content is an important soil characteristic. It is called pF curve or water retention curve. The pF curve depends on soil intrinsic properties like grain size distribution, type of minerals, type and amount of organic matter, and on soil structure. Often, it is said that pF2 (100cm suction) is the wettest soil state that can exist under draining conditions during more than one day (field capacity). When the soil has been dried to pF4.2 plant roots are not able any more to extract water from the soil. The amount of water that the soil looses (can supply to plants) when it dries from pF2 to pF4.2 (available water holding capacity AWHC) is an important parameter for plant growth. AWHC can be derived from the pF curve. For example, Fig. 18 is a pF curve derived for location 002-40-118. Graphically, it can be measured from the curve that for this curve AWHC = 0.183 cm3/cm3.

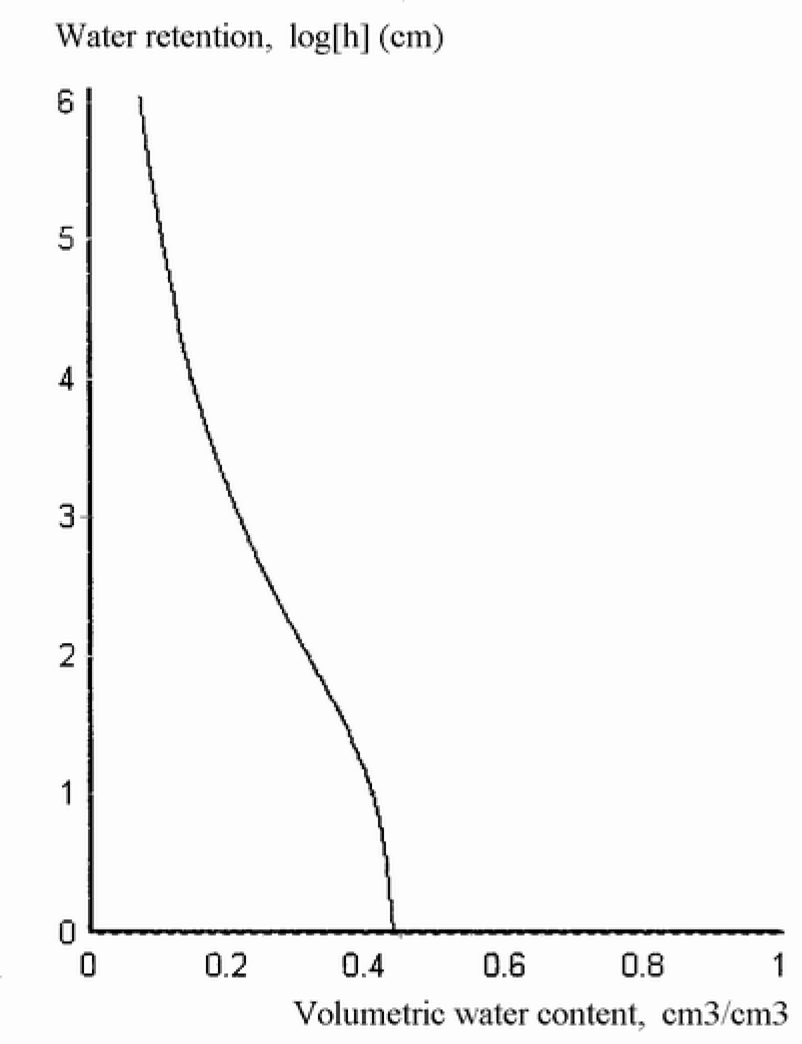

Fig. 18. Example of a pF curve

Measuring pF curves needs expensive equipment and experiments. Fortunately, there exist so-called pedotransferfunctions allowing the derivation of pF curves from simple soil properties. The pedotransferfunctions from Woesten et al. (2001) were used to establish pF curves for a number of objects. These functions needed median of the sand fraction, percentage of particles smaller than 0.050mm, percentage of particles smaler than 0.002mm, and organic matter content. For each of the curves, AWHC was determined. The results are:

1999-7	0.183 cm3/cm3
1999-9	0.198
1999-10	0.183

1999-11	0.183
1999-12	0.183
1999-15	0.175
1999-16	0.183
1999-18	0.179

002-0-19	0.206
002-19-40	0.183
002-40-118	0.183
003-0-25	0.243
003-25-89	0.167
007-0-65	0.294
005-0-21	0.183
005-21-53	0.175
005-53-100	0.167
0010-0-65	0.278

Woesten et al. (2002) discussed the accuracy of pedotransferfuctions. The above AWHC values, estimated by the pedotransfer-functions, ranged from 0.167 to 0.294 (cm^3 cm^{-3}). We could not find a correlation between these values and LDI (Leaf Drying Index) values, probably because AWHC is only one of the factors that determine water supply. The average value is 0.197 . Average values are more accurate than values for individual sites (Woesten et al., 2002). The value 0.197 applies to soil samples from zones that were enriched with peat at tree planting. As mean soil quality of the entire root zone is likely less, we estimated the average AWHC of the tree root zones as ¾ of 0.197 = 0.15 . AWHC is one component in a water balance that can be made for the studied tree – grass - root zone system. Assuming root zone depth = 1m, the estimated available water capacity can be expressed as 150mm water. The available water in the root zone during the growing season is equal to the amount of water that is present at the start of the growing season (150mm) plus the rainfall during the growing season (400mm) minus interception by tree (30% of rainfall = 120mm) and grass leaves (15% of rainfall = 60mm). So, the available water in the root zone during the growing season = 370mm. Precise hydrological data for Moscow are scarce. Assuming Moscow and Dutch conditions are similar: the potential water take up by the tree in the growing season may be estimated as 675mm (0.3 X E_0 X LAI where E_0 = 500mm in an average Dutch growing season, and LAI is Leaf Area Index, being 4.5 for a rather usual tree; Bakker, 1992); and the potential water take up by the grass in the growing season may be estimated as 340mm (400mm – Interception by grass canopy; Hellinga, 1962). So, the potential water take up of tree and grass from root zone is 675 + 340 = 1015mm. This value can be compared with the available water in the root zone during the growing season (370mm). This 370mm is 36.5% of the 1015mm. The derived water balance, applying to an "average situation in Moscow" is summarized below.

Actual transpiration:

Initial available water in root zone:	+ 150mm
Rainfall:	+ 400mm
Interception by tree leaves:	- 120mm
Interception by grass leaves:	- 60mm
	370mm

Potential transpiration:

Tree: 0.3xEoxLAI	675mm
Grass:	340mm
	1015mm

Actual transpiration = 36.5% of potential transpiration

Bakker (1992) states that a forest tree in Dutch conditions should transpire 50-75 % of its potential transpiration in order to stay alive and decorative. This corresponds with a growth rate of 40%. The above water balance shows that, for Moscow trees, incidence of water stress is very likely. At the same time it should be realized that the water balance is not very accurate. Root zones may be larger, and flow of rainwater from surfaces outside the root zone surface may contribute to the root zone water. Leaf Area Index may be lower due to stress.

4.3. Chemical toxicity and urban trees.

4.3.1. Introductory remarks.

Beginning with 60-s ecologists and soil scientists are interested in the problem of the city soil pollution with different pollutants. Pollutants are the chemical compounds the heightened amount of which in the biosphere and its components causes the toxico-ecological situation. They are:

- heavy metals;
- soluble toxic salts;
- pesticides;
- mineral oil and oil products;
- phenol;
- carcinogenic substances;
- cyanides;
- radioactive substances;
- macrochemical fertilizers;
- individual microbial pollutants.

According to the published data the growth of the environmental pollution with heavy metals and metalloids is one of the greatest city problems. The main pollutants are manganese, chrom, lead, zinc, copper, nickel, cobalt, cadmium, fluorine, arsenic (Methodical directions on the estimate…, 1999). According to a number of investigators in Moscow another very important factor that impacts the plant status are soluble salts, which are used as antiicing mixture. As ice melts these salts penetrate into soil and cause salting. Using of the antiicing salt mixtures causes not only the salting, but also the forming of the soil salinization – a very detrimental factor for the plant growth. Ca^{+2}, Mg^{+2}, Na^{+2} are already steady components in the adsorbing complex of the Moscow soil. Sodium is present mainly as NaCl in the soil solution. Limiting and abnormal concentration of chemical elements and their compounds in the soil becomes too frequent phenomenon. Shiskov et al. (1989) indicate the following sources of the detrimental material advance into the city soils: construction and destruction of buildings, blow-outs from metallurgical enterprises, power plants, oil refineries, chemical enterprises, waste water, municipal pollutants, transport.

Transport is admitted to be one of the main sources of pollution. Experts count about 40 chemical elements. The most part of them are toxic. It is established that the following elements are especially toxic; Cu, Cd, Co, Ag, Be, Sn, Cr, As, Ni, Pb, Mo, Hg, Ta (Shishov et al., 1989; Cabata-Pendias and Pendias, 1989). (Table 16).

Table 16. Pollutants Danger Classes

Danger Class	**Chemical**
1.	Arsenic, cadmium, selenium, lead, zinc, fluorine
2.	Boron, cobalt, nickel, molybdenum, iron, stibium, chromium
3.	Barium, vanadium, wolfram, manganese, strontium.

Atmospheric and soil pollutants greatly affect the plant status and the soil fertility. According to the published data they may cause:

- decrease of the tree growth in diameter and height;
- decrease of fruitage; reduction of generative organs
- harvest decrease;
- root growth oppression;
- decrease of the needles lifetime;
- reduction of the assimilating surface of the tree crown;
- acceleration of the aging process and the plant reduction;
- soil destruction;
- decrease of the biochemical activity of the soil organisms;
- ecological function upset of the micro-organism association;
- reduction of the form diversity of micro-organisms.

It is derived that the presence of heavy metals in the soil is practically eternal. Metals accumulated in the soils slowly move away under the soil leaching, plant consumption, erosion and deflation. The first heavy metal half-period (or the time of moving away of 50% initial concentration) for soils varies highly. It accounts: for zinc – from 70 to 510 years, for cadmium – from 13 to 1100 years, for copper – from 310 to 1500 years and for lead – from 740 to 5900 years (Cabata-Pendias and Pendias, 1989; Galaktionova, 1993a, 1993b; Thornton, 1985; Glazovskaya, 1981, 1984).

According to Obuhov A..N. and Lepneva O.M. in Moscow soils the B, Mn, Ni, V, Y, Yb, Zr, Ti, Sr, Mo content is most often within the limits, typical for soddy-podzolic soil of the zone. Only some content of Sn and Cr is indicated. In controlling the city environment status there is more information on the content of Zn, Pb, Cu, Cd in the soil. The content of these metals in the lawn soil along the highways averages (mg/kg):

60 for Pb, 230 for Zn, 80 for Cu, 0,7 for Cd. It is 4-6 times higher than typical for soddy-podzolic soil.(Obuhov and Lepneva, 1989, 1990).

The results of many investigations by different authors (Stroganova, 1997; Obuhov and Lepneva, 1989; Ecological investigations…, 1998) indicate that the soil pollution level is different in different parts of the city. According to the tests the soil of the city centre is the most polluted. The pollution level is twice higher there than on the average in the middle part of the city and 3 times higher than in the outlying districts. The soil pollution level in the centre is estimated as highly dangerous (emergency ecological state), in the middle part of the city – as dangerous (critical ecological state) and in the outlying districts – as moderate dangerous (tense ecological state). As further to the outlying districts from the centre of the city the decrease of the soil pollution is observed practically in all forms of greenery. As approaching the centre of the city at increase of the soil pollution the variability of the heavy metal content in the soil also increases from 20-30% to 40-50%. The variability and dynamics of the heavy metal content in the soil is higher as higher the level of their technogenic formation. Their high variability also can be accounted for the unevenness of the pollutant fall-outs and their further penetration and redistribution in the soil under the impact of the natural and anthropogegic factors (Obuhov and Lepneva, 1989).

The heavy metal content in the lawns along highways naturally depends on the distance from the road-bed. According to Obuhov and Lepneva (1989), the highest level of the heavy metal content was observed in the grass-plots separating two road-beds of the double-sided highways (with double-way movement). Low level of heavy metal content is typical for the soil by the curb and at a distance of about 2 m from the road-bed. This phenomenon can be explained by the particularities of the road and lawn maintenance during the whole year. In winter a great amount of sand enters the highway roadside. The level of the heavy metal content at the sides of the lawn may decrease as a result of pure dilution with the sand, which is free of heavy metals. From the other side, the decrease of HM content may be caused by the sand mechanical migration. During the lawn cleaning, which is usually held after snow melting, sand, peat crumbs and partially the surface soil are taken away from the pre-road sides of the lawn. Thus it prevents the HM accumulation. In the central parts of the lawn heavy metals are accumulated because of the high retention capability of humus.

This regularity doesn't occur at the spread of the heavy metal movable compounds in the soil. The heavy metal content extracted by the acetat-ammonia buffer solution is practically steady in the lawn soil and doesn't depend on the distance from the road-bed (Lepneva and Obuhov, 1989). The amount of movable, accessible to the plants heavy metal compounds depends on the pH index. According to Lepneva and Obuhov (1990), at the pH index less than 4,8 the amount of movable forms of the heavy metal compounds is 10 times and more higher than the phone index. According to these data the quota of the movable forms of the heavy metal compounds comparatively to the gross content averages 20% for lead, 30% for zinc and 10% for copper. The unpolluted soils of the zone-genetic series accounts only for 2-5% heavy metal movable compounds as against their gross stock.

According to many authors maximum amount of heavy metals is concentrated in the upper 10 cm layer of the soil (Galactionova, 1993). Their gradual accumulation in this layer tends to the chemical and physico-chemical changes of the city soil features (Stroganova, 1997).

Titov et al. (1996) suggested quite an interesting method of estimation of the heavy metal mobility in the technogenically polluted soil. This method is based on the determination of the heavy metal content in organic-mineral fractions of different size and density preliminary extracted from the soil by the method of granule-densimetric fractionating. According to the data Cu, Pb, Co, Cd on entering the soil are accumulated in the dust and muddy soil fractions. So their content in the thin-dispersed fractions is more informative in terms of the estimation of the soil pollution with heavy metals in comparison with the existent criteria. Thus in the dusty fractions copper concentration is 3-5 times, lead – 1,5-7,6 times higher than in the soil on the whole. In the muddy fraction cadmium content is 1,5 and lead is 3…10 times higher than in the soil on the whole.

In the opinion of a number of authors, lead is one of the main and dangerous polluters. (Grigoryeva, 1980; Lepneva and Obuchov, 1990; Nikiforova, 1983; Glazovskaya, 1994). The majority of lead compounds are of little mobility, that's why the danger of accumulation of the technogenic lead in the soil is rather serious. In the industrial aerosols lead has the form of PbS, PbO, $PbSO_4$, in the exhausted gas it has the form of halides Pb(OH)Br, $(PbO_2)B_1B_2$, PbB_2, etc. Halides are unsteady and transit easily into oxides, carbonates, sulphates. In aerosol extracts some part of lead has soluble form and the quota of this form increases with the distance from the source of the pollution by 25-50% and even by 76%.

Lead transit forms and compounds, bonded with the manganese and ferric oxide, constitute the major part of the aerosol falls (25-50%). The part of the lead compounds that is not extracted by neutral salt solutions, mineral acids and acetate–buffer mixture even just near the source of the pollution (the city environment, a lead ore preparator) totals only 2-5% of the whole metal mass. (Glazovskaya, 1994).

The majority of the lead compounds are soluble with difficulty with the exception of lead hydroxide ($Pb(OH)_2$), solubility of which is about equal to the ferrous compound ($Fe(OH)_2$) solubility and significantly higher than $Fe(OH)_3$. It is supposed that in the soils with the reproducing regime the movability of bivalent ferrum and lead hydroxides is practically equal. Ortho-phosphates and lead sulphates are soluble with particular difficulty. The pH index impacts considerably the degree of solubility of the lead compounds. All lead compounds are most soluble at low pH indices ($pH<4$). Within pH 6,5-8,0 the solubility decreases sharply, with further growth of pH it increases again and it is especially noticeable for ortho-phosphates and pyromorphite lead compounds ($(Pb_5PO_4)_3OH$, $Pb_5(PO_4)_3Cl$). The phosphate solubility depends on the concentration of the anion PO_4^{3-} in the solution, and the carbonate solution depends on the CO_2 atmospheric pressure level.

The test data of vegetation and field trials show that limiting concentration (LC) of lead in the soils depends on the whole complex of soil-ecology conditions, among which the soil reaction and humus content are particularly important (Grigoryeva, 1980; Nikiforova, 1983). Acid-alkaline conditions impact the lead availability for plants. If lead LC level in the dry plantation mass is assumed to be 10 mg/kg, the LC indices of lead in soils may vary from 150 mg/kg in acid soddy-podzolic soils to 500-2000 mg/kg in neutral and sub-alkaline soils with high content of the organic substance. It is natural to expect that the soil cultivation, increasing of humus amount in it, liming help the soils and the plants to resist lead intoxication (Glazovskaya, 1994).

The aerosol begins to transfer from the very moment of falling on the plant greenery while passing through the vegetation cover (Arkhipova and Yelpatyevski, 1990). The transformation goes on with passing through the layers of the slow-rotting residues (litter, peat), humus soil layers and further into the deeper layers of the soil bulk. On this way the relations between the lead compounds, which have the form of the true or colloid solution and the form of suspension, undergo changes (Arkhipova and Yelpatyevski, 1990).

The whole metal mass in the soil water decreases when passing through the soil bulk and (according to the results of the analysis of the acid soils with the washing water regime held in the moderate zone of Euroasia and Northern America) it doesn’t exceed 3-6% of the soluble lead volume, falling with the aerosol flow in the natural environment, and 1-2% in the zones of active technogenic environment (Arkhipova and Yelpatyevski, 1990).

To evaluate the soil quality at research sites, we conducted agro-chemical soil analysis, analysis of the content of flexible forms of heavy metals in the soil, analysis of water soluble salts in the urban soil, analysis of heavy metals content in leaves of urban trees, and analysis of salt content in leaves of urban trees.

4.3.2. Agro-chemical soil data and tree condition.

The results of the agro-chemical analysis of soil are given in Table 17.

Table 17. Moscow Soil Agro-Chemical Characteristics

State of trees, top drying percentage	**Sampling depth, cm**	**PH_{KCl}**	**Ca++**	**Mg++**	**P2O5**	**K2O**
			mg per 100 g of dry soil		**mg per 100 g of dry soil**	
<25%	0-20	7,41	43,00	1,36	17,40	12,76
	20-40	7,58	29,02	2,80	12,50	9,39
	40-60	7,58	31,76	1,31	5,78	12,76
	60-100	7,78	32,35	1,50	8,25	12,04
	Average data		**34,03**	**1,74**	**10,98**	**11,74**
25 – 50%	0-20	6,89	22,31	1,31	82,50	40,33
	20-40	7,35	26,37	1,78	16,45	15,41
	40-60	7,26	22,47	2,68	17,90	14,45
	60-80	6,89	8,81	0,55	11,20	13,72
	80-100	7,24	21,00	1,29	2,61	18,06
	Average data		**20,19**	**1,52**	**26,13**	**20,39**
50-75%	0-20	7,42	24,08	2,06	1,88	10,60
	20-40	7,53	66,38	3,85	8,00	11,31
	40-60	7,30	58,01	1,98	7,75	9,87
	60-76	7,50	55,56	2,07	5,75	13,72
	76-100	7,54	57,98	2,19	7,50	9,87
	100-120	7,50	26,25	1,32	2,49	9,39
	Average data		**48,04**	**2,25**	**5,56**	**10,79**
>75%	0-20	7,49	48,96	2,49	6,50	13,72
	20-40	7,41	22,71	1,86	2,61	9,87
	40-53	7,53	30,04	1,63	2,31	8,48
	53-66	7,06	23,14	2,75	N/A	13,72
	66-78	7,45	37,36	1,39	4,05	12,04
	78-96	7,36	20,44	1,43	1,63	7,70
	96-110	7,37	14,81	1,22	1,12	7,70
	Average data		**28,21**	**1,82**	**3,04**	**10,46**

According to the data from Table 17, the quality of the roadside soil is rather unsatisfactory (> 75% branch drying) and of rather poor fertility. The contents of mobile potassium and phosphorus and also the content of humus are very low. The contents of the calcium and magnesium cations in the adsorbing complex of the soil are also low.

The level of the fertility is higher in the soil under the plants with satisfactory (up to 25% branch drying) and relatively satisfactory (25 - 50%) status. These soils are well provided with biologically active macroelements (potassium and phosphorus) which may be caused by fertilization and municipal pollution. The content of calcium and magnesium cations in the adsorbing complex of the soil is high. Many authors connect this fact with calcium chloride, which is used for the road and pavement covering in winter and which then enters the soil through the upper layer with the drainage water. The other cause is the release of calcium under the impact of acid fallout from construction waste cement, bricks, etc. (Lepneva and Obuhov, 1989).

According to obtained data, the law is obvious that the content of mobile potassium and phosphorus increase in the soil under moderately weakened trees (40% of top drying). The content of these elements drastically drops in the siol under trees in a very poor state (Fig. 19 and 20).

The data (Table 17) show that in the road-side city soil there is no clear differentiation of acidity, humus, and movable forms of macroelements coordinated in cross-section with the natural one, that is their level doesn't decrease with depth (this also the case with movable forms of heavy metals). As a rule there is no objective regularity. It is concerned with the fact that the lack of genetical layers is typical for these soils. In the soil cross-section artificial layers, different in colour and thickness, are combined. It is indicated by sharp transition from one layer to another and even boundaries between them. There is a lot of municipal and construction waste in the filling layers (brick crumbs, asphalt pieces, broken glass, coal, etc.), which is combined with the industrial waste, peat-compost mixture or the natural layer fragments.

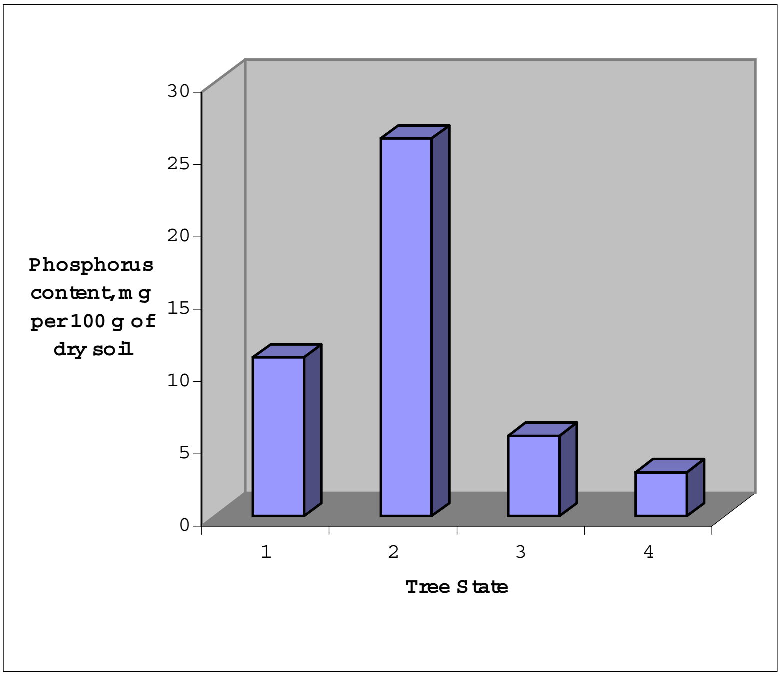

Fig. 19. Mobile phosphorus content in soils under trees in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

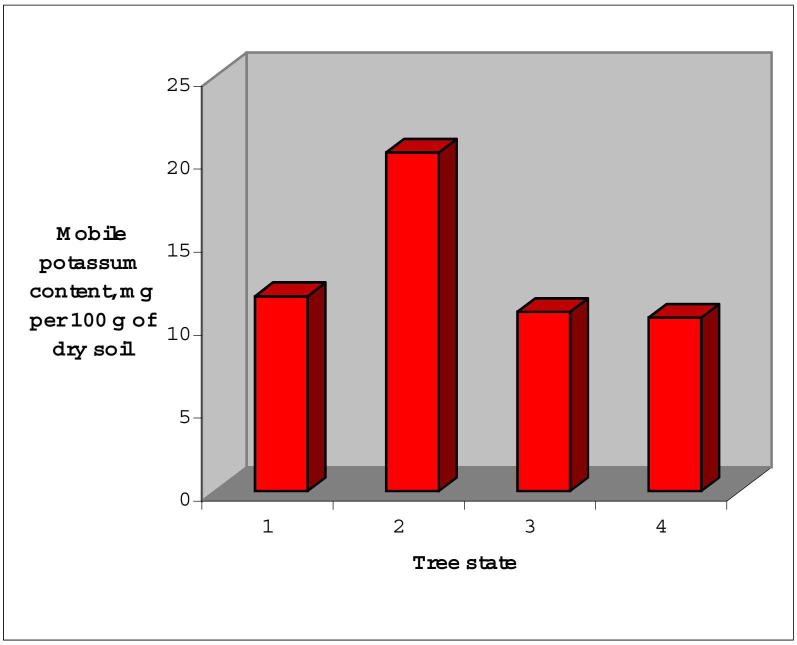

Fig. 20. Mobile potassium content in soils under trees in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately

weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

4.3.3. Heavy metals in the soil and tree condition.

Heavy metals (or microelements) are essential for plants in small amounts. At present it is known that ten microelements are vital for all plants for certain, some more are vital only for some species. It is known about other elements that they stimulate the plant growth, but their functions are not determined yet. Typical for them is that, even if they are essential for the plant growth, in high concentration they can have a toxic impact on the cells. Some heavy metals are not essential for plants, but at the same time they are very detrimental even at low concentration.

Vital elements are the elements, which can't be substituted because of their specific biochemical role and which have direct impact on the organism as it can't neither grow nor fulfill some metabolic cycles without them. If the supply of some vital microelement is insufficient, the growth of the plant becomes abnormal or terminates, its further development, especially its metabolic cycles, are violated. The metabolic upset can be caused both by a lack and an excess of minor nutrients. On the whole plants sustain more easily high than low concentrations of the elements. But though plants quickly adapt to the chemical stresses they can be sometimes very sensitive to the excess of a separate element.

Data on mobile forms of heavy metals in soil of urban trees are given in Table 18.

Table 18. Heavy metals Content in Moscow Soil (Average in Soil Layers)

Tree State, Top Drying Percentage	**Pb**	**Co**	**Mn**	**Ni**	**Cu**	**Zn**	**Cd**	**Fe**
	Ppm/humus%							
<25%	1,19	0,04	2,24	0,10	0,53	4,41	0,06	2,67
> 75%	**4,52**	**0,19**	**14,46**	**0,26**	**0,85**	**21,38**	0,12	**8,9**
25 – 50%	0,74	0,11	7,32	0,15	0,44	1,40	0,11	4,07
50 –75%	**1,82**	0,11	**11,77**	0,18	0,41	8,60	0,10	4,24

As is shown in Table 18, accumulation of mobile forms of heavy metals, such as lead, cobalt, manganese, nickel, copper, zinc, iron, is observed in soils under trees in very poor state. This statement is the most clearly illustrated in Fig. 21, 22, and 23.

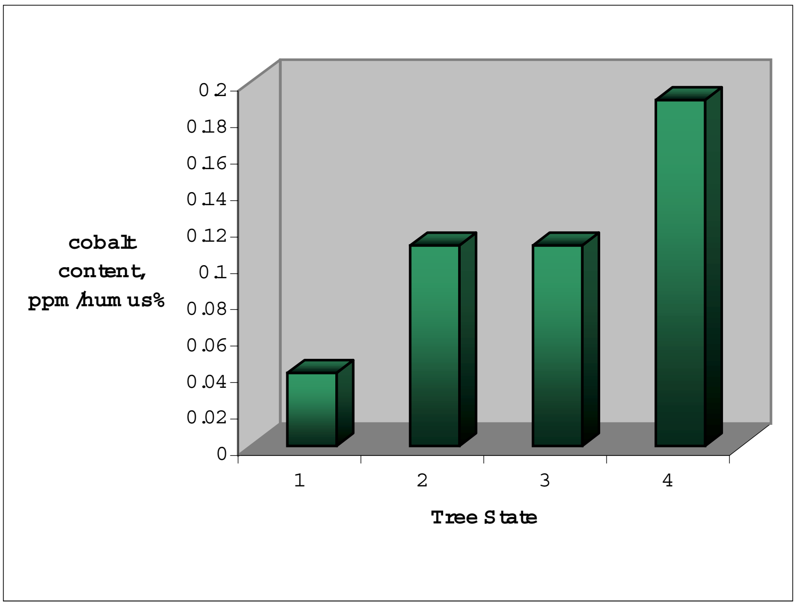

Fig. 21. Mobile cobalt content in soil under trees in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

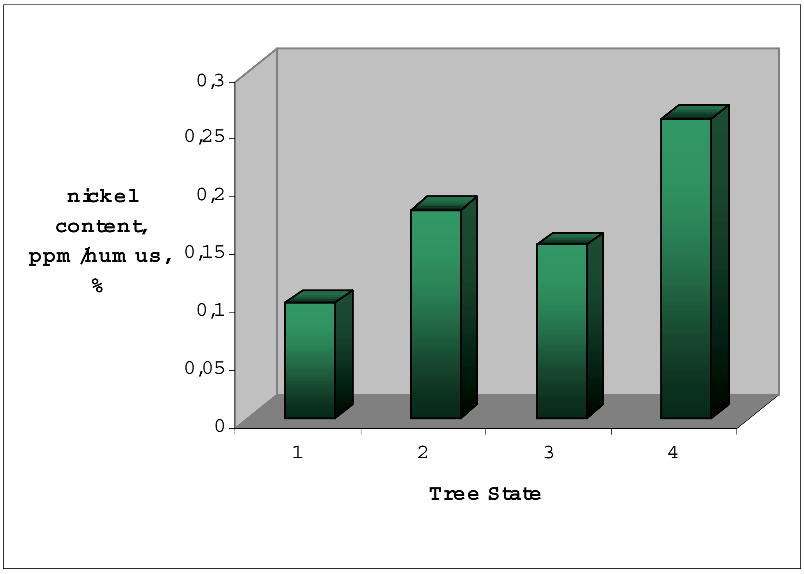

Fig. 22. Mobile nickel content in soil under trees in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

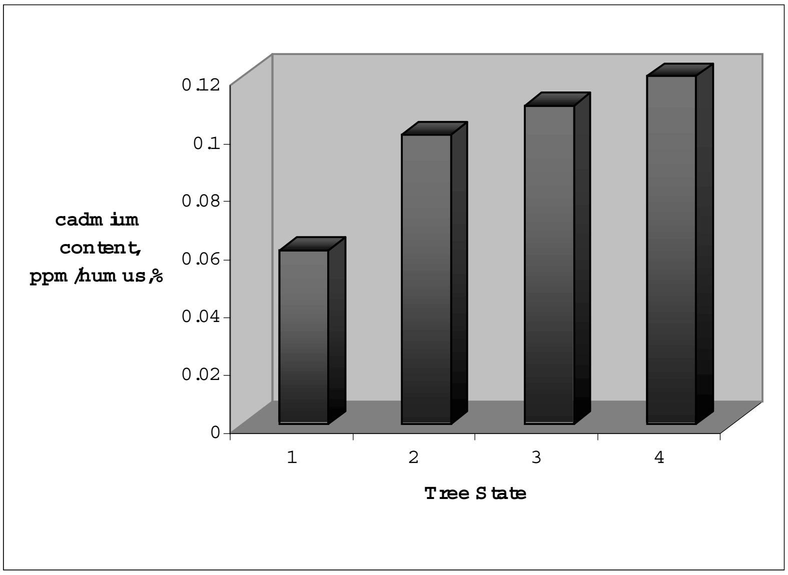

Fig. 23. Mobile cadmium content in soil under trees in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

4.3.4. Water soluble salts in the urban soil and tree condition.

The problem of impact of de-icing mixtures on the environment, first of all, on greenery, arose comparatively recently, but its consequences are already so significant that the necessity arose to conduct special research to detect alternative methods to combat snow and ice and to develop new standards, being confronted with impossibility to give up using salts in expensive cities (Hofstra, 1976; Meyer, 1996; Dirr, 1976; Ecogeochemistry of the city…, 1995).

Salts started to be employed in Moscow in 1960's, not in pure form but as a mixture of sand and salt where the content of salt was at least 10%. The main reagent recommended for combating snow and ice on roads was calcium chloride. But its high corrosive ability and negative impact on the greenery growth lead to the necessity to search for a way to modify this reagent in order to allow reduction or elimination of the above defects (Ecological investigations.., 1998).

Numerous attempts were made to give up using salt at all. For instance, it was tried to adapt Finnish method of using granite scraps as de-icing means. In Moscow, this initiative had no success due to drainage system being stuffed with granite scraps. One had to get back to using sand and salt mixture, which did not take root either due to drainage system – though it was considered cheaper and sparing to the environment.

Sand and salt mixtures, with insignificant content of salt, had been used in Moscow till 1993. Since 1995, liquid calcium chloride has been used as the basic de-icing material. As a result, salinization of soils by chlorides in several Moscow regions was found.

1997 analyses of samples of de-icing mixtures showed that they mostly consist of NaCl (97%) and potassium.

Up to now, all soils in Moscow have been found to be salinized to some extent. Sanilization of soils is the most common along highways. Salinized soils are also met with in squares, boulevards, and yards.

We have also obtained results that testify too high concentration of salts in urban soils (see Table 19).

Table 19. Average Values of Na+ and Cl- ions under Trees in Different State

Tree State, Top Drying Percentage	**Na^+**	**Cl^-**
	mg/kg	
<25%	54,9	0
25 - 50%	76,3	0
50 – 75%	139,7	89
> 75%	463,8	252

According to the data given in Table 19, the regularity of increase of Na+ and Cl- ions in the soil under trees in a very poor state (>75% drying branches) is well seen. For instance, Na+ ion content in the soil under trees in satisfactory state (<25% drying branches) reaches 54.9 mg/kg, whereas it almost 9 times as much under trees in very poor state.

4.3.5. Heavy metals content in leaves of urban trees and tree condition.

The complex analysis of soils and plants is the most widely spread method of the plant status diagnostics (Burg, 1990; Hewitt, 1974; Kopinga and Burg, 1995). Both a lack and toxicity of the microelements can be caused by the complex interdependence of several factors, which may change depending on specific environmental features. A great number of observations and experiments, which took place in different countries on different types of soil, displayed clearly that genesis and soil features are the main factors that control the occurrence of the micro-element deficit and in many cases of the micro-element excess.

That's why side by side with the diagnostics of the soil chemical features the leaf diagnostics of the plant was held. The chemical analysis of the plant shows, which nutrients are available to it and which are not. Leaves in this case serve as a good analytic character, as just here in the leaves the organic substances are formed, which spread all over the plant and later feed all the organs of the plant. Roots supply leaves with mineral salts. Under the action of light salts, carbonic acid and water develop in the leaves into new organic substances (Tserling, 1990).

Leaves of small-leaved linden were found to contain the following micro-elements: Mg, Al, Si, P, S, K, Ca, Zn, Hg, As, Se, Sr, Br, Mn, Pb, Fe, Ni, Cr, Cu, and Ca, Mg, Cl, N, P, Na, K.

We also detected relationships between the tree state and content of these elements in leaves. We found some correlation between top drying and heavy metals accumulation in leaves for the following elements: chromium, bromine, lead, rubidium and nickel (Table 20). Note that, in this Table, contents are expressed as ppm per cm^2 leaf area.

Table 20. Heavy Metals Content in Leaves of Small-Leaved Linden (average values, 2000)

Tree State, top drying percentage	**Cr**	**Br**	**Pb**	**Rb**	**Ni**
	ppm/cm2				
<25%	0,38	0,13	0,17	0,17	0,17
25 –50%	0,48	0,18	0,18	0,18	0,16
50 – 75%	1,84	0,19	0,35	0,4	0,20
> 75	2,61	0,32	0,39	0,54	0,30

According to Table 20, one can trace some regularity of accumulation of Cr, Br, Pb, Rb, Ni in leaves of linden growing along highways. The greatest content of these elements is observed in trees in extremely poor state (>75% drying branches).

Presenting the obtained data in Table 20 in the form of charts, and fitting curves through the plotted data, one can observe an interesting regularity (Fig. 24, 25, 26, 27, 28). Obviously, accumulation of these elements does not produce substantial impact on moderately weakened trees (up to 25 - 50% drying branches). Breakage is observed in trees with top drying that ranges from 25 - 50%. There is all evidence that trees with 50% of top drying on average are the most sensible to HM accumulation in leaves. One can suppose that for leaves in relatively satisfactory state (up to 25 - 50% drying branches) heavy metals play the role of micro-fertilizers. A higher content of heavy metals in leaves functions as toxins, accumulation of which is detrimental for trees. Reasons for top drying in trees in a relatively poor state may also be other factors.

The findings give a reason to suppose that an increase in heavy metals by 10%-20% from their content in leaves of trees in satisfactory state will not produce considerable impact on decorative nature of urban trees.

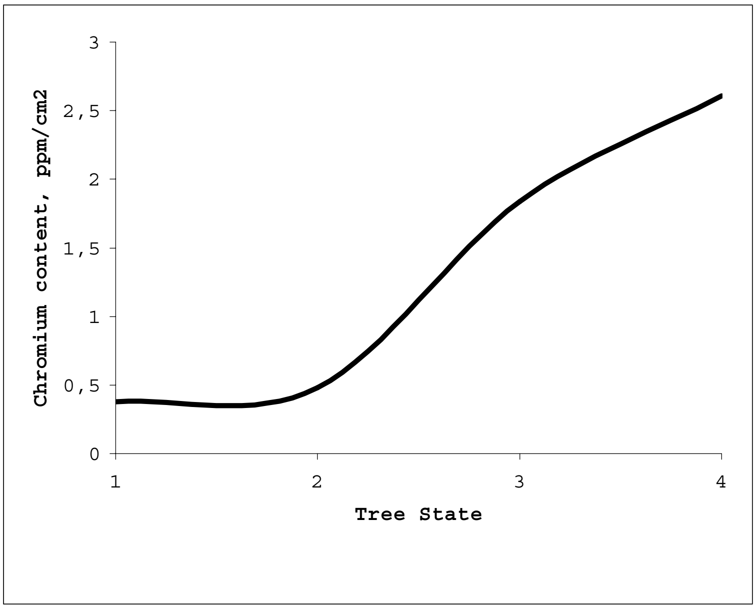

Fig.24. Chromium content in leaves of small-leaved linden in different state. 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

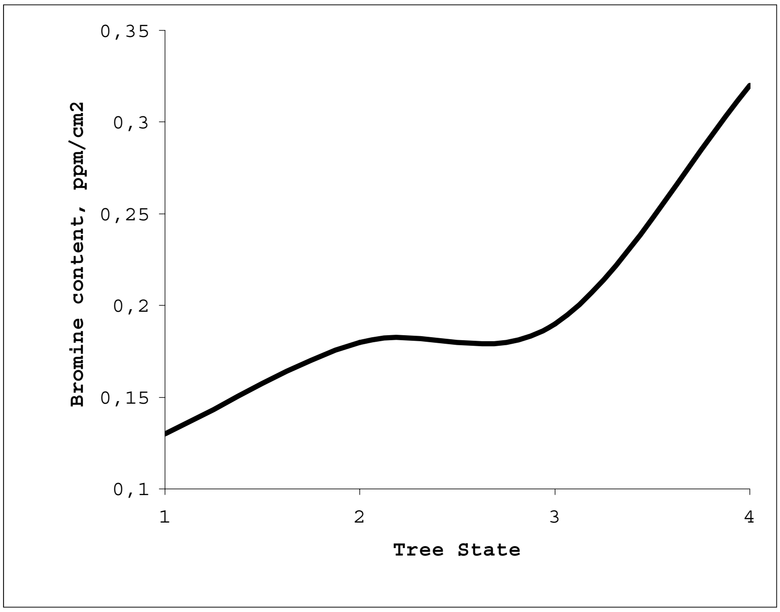

Fig. 25. Bromine content in leaves of small-leaved linden in different state. 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

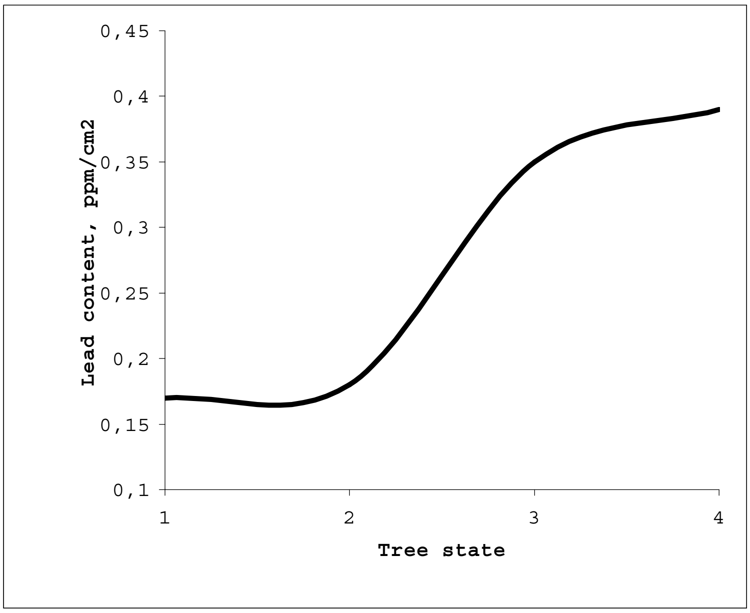

Fig. 26. Lead content in leaves of small-leaved linden in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

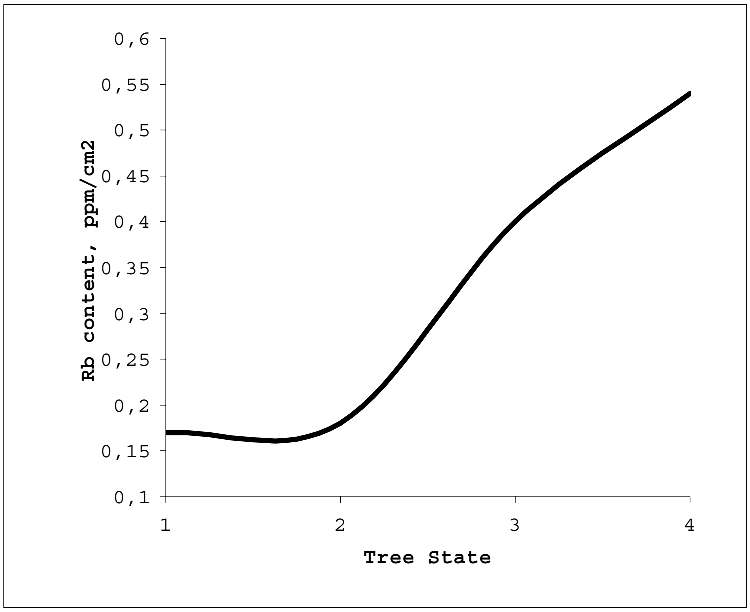

Fig.27. Rb content in leaves of small-leaved linden in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

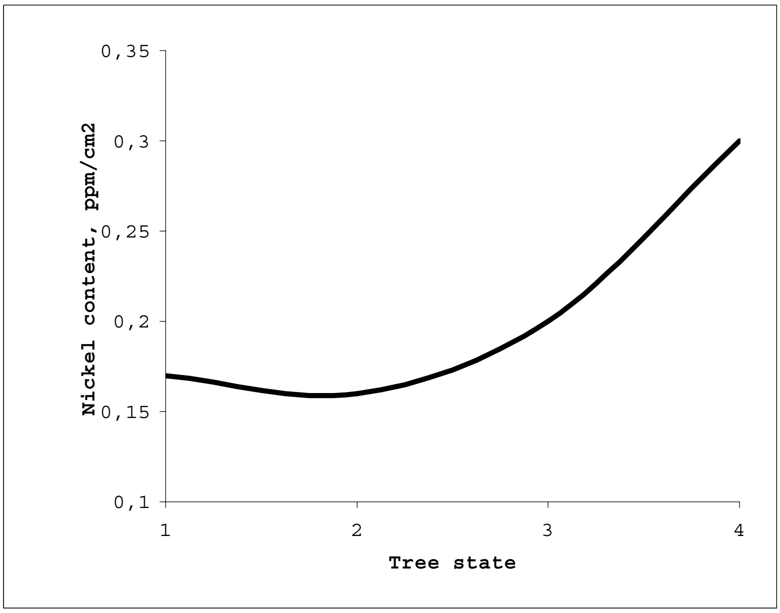

Fig.28. Nickel content in leaves of small-leaved linden in different state.): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - moderately weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – moderately drying trees with branch drying over 75%.

4.3.6. Salt contents in leaves of urban trees and tree condition.

According to numerous domestic data, one of the key factors that influence the plant state is water soluble salt used in winter as de-icing mixture.

As is known, salts penetrate the soil in different ways. Use of salt in winter sparks the boost in its content in snow. Thawing snow partially flows to surface waters, which invites surge in river water mineralization in spring, and often to soil, which leads to its salinization.

Directly from roads, salt splashes from below the wheels of cars, fall on lawns and salinizes soil, whereas aerosols of water and salt mixture are scattered by wind across the adjacent territory and spread to 30 – 200 m. Mechanical barriers (buildings and trees) diminish the distance of transfer of aerosols of salt and water mixture, boosting its concentration off roads. During snow-ploughing of highways, the bulk of salts also falls onto the soil, which is most often connected with violation of plough technology.

Trees and bushes retain salts on leaves and branches, being a mechanical barrier to distribution of water and salt mixture by air, which hinders transpiration and respiration of leaves. When soil is salinized, high content of salts in leaves of trees and external signs of salt poisoning are observed.

Negative effect of salts on plants is complex. It includes, at least, two components: osmotic and toxic. Osmotic action is expressed in reduced water absorption and unfavorable change in water and salt exchange in cells and tissues. Water deficiency in tissues, being a result of osmotic action of salts, may be aggravated by their toxicity when ions are excessively accumulated in cell cytoplasm. In this case, both direct and indirect toxic impact of ions may be observed. Visual signs of toxicity may be observed by formation of necroses on leaves and stalks. As a rule, such salt effect is well expressed in sudden surge of salt concentration in the environment. As salts accumulate in plants, viability of these falls, and weakened plants are subject to different phyto-pathogens and technogenic factors to even greater extent.

Results of chemical analysis of linden leaves suggest that trees growing along highways accumulate significant quantities of sodium and chlorine (Table 21).

Table 21. Average Values of Several Chemical Elements in Leaves of Small-Leaved Linden in Different State.

Tree State, Top Drying Percentage	**Nitrogen**	**Phosphorus**	Sodium	**Potassium**	**Calcium**	**Magnesium**	**Chlorine**
	g/kg						
	1999						
<25%	25,10	1,77	0,12	17,13	13,15	3,13	7,06
	34,68	1,98	0,14	15,17	13,35	2,62	8,31
	29,33	2,29	N/A	16,34	12,07	2,70	
	33,04	2,26	0,09	18,53	10,63	1,80	6,14
Average values	**30,54**	**2,08**	**0,12**	**16,79**	**12,30**	**2,56**	**7,17**
25 - 50%	28,42	2,48	0,39	16,62	14,96	1,82	7,03
	34,33	2,11	0,30	15,17	16,20	2,77	11,61
Average values	**31,37**	**2,29**	**0,35**	**15,89**	**15,58**	**2,30**	**9,32**
> 75%	31,14	2,45	1,79	16,11	15,16	2,99	13,85
	33,94	2,11	3,45	13,88	16,08	3,50	12,60
Average values	**32,54**	**2,28**	**2,62**	**14,99**	**15,62**	**3,24**	**13,22**
2000							
<25%	32,44	2,36	0,12	16,73	16,76	3,84	3,62
	33,12	3,07	0,41	19,71	15,92	2,62	4,12
	37,62	2,45	0,32	20,72	13,83	4,20	3,23
Average values	**34,39**	**2,62**	**0,28**	**19,05**	**15,51**	**3,56**	**3,66**
25 – 50%	31,52	2,46	**0,35**	16,04	15,08	2,64	**9,19**
50 – 75%	26,14	2,60	**3,59**	16,07	17,24	1,53	**9,80**
> 75%	33,05	1,86	**3,52**	18,77	**12,67**	**1,26**	**10,65**

Notes: weakened trees with branch drying of less than 25%, 1 – moderately weakened trees with branch drying that ranges from 25% to 50%; severely weakened trees with the percentage of branch drying that ranges from 50% to 75%; drying trees with branch drying over 75%.

As is obvious from data in Table 19, really considerable impact on the tree state is made by Na+ and Cl- ions. The worse the tree state the more Na+ and Cl- ions are accumulated in leaves of a plant.

It is to note our findings obtained during chemical analysis of leaves of the trees growing on the shady side of highways (see Table 22).

Table 22. Average Values of Na+ and Cl- Ions Content in Leaves of Trees Growing on the Shady Side of Highways.

Tree State, Top Drying Percentage	**Na^+**	**Cl^-**
	g/kg	
<25%	0,37	5,27
25 - 50%	0,77	6,85

Note: weakened trees with branch drying percentage of less than 25%, moderately weakened trees with branch drying percentage that ranges from 25% to 50%.

Comparing the content of Na+ and Cl- ions in leaves of trees growing on the sunny and shady sides, it is easy to notice that the quantity of these ions in leaves is different (Fig. 29)

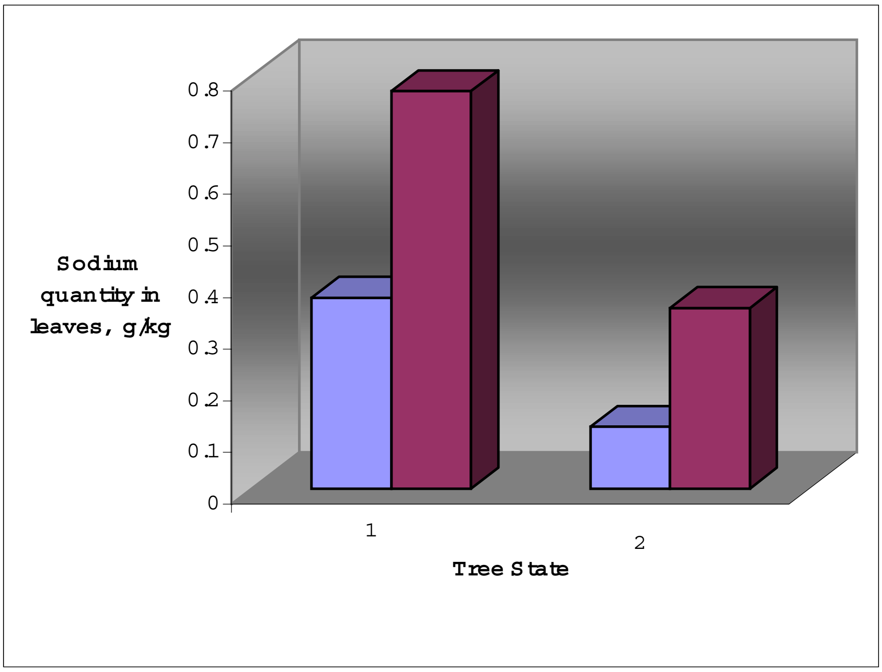

Fig. 29. Na- ion content (g/kg) in leaves of trees growing on the sunny and shady side of highways. 1 - < 25% drying leaves, 2 - 25 – 50% drying leaves. Small part of the data is measured in1999. The larger part in 2000.

The regularity is fairly well seen: trees growing on the shady side of highways and having a satisfactory state (25% top drying) accumulate more Na+ and Cl- ions. Trees with < 25% branch drying that grow on the sunny side of highways contain lower quantities of these ions. Proceeding from the above, one can suppose that action of Na+ and Cl- increases under sunlight. Therefore, a linden growing on the sunny side of highways will suffer from a lesser content of Na+ and Cl- ions in leaves than a linden growing in the shady side.

4.4. Relationships between tree parameters and tree condition.

4.4.1. Introductory remarks.

The state of trees was evaluated in the following parameters:

- length of the last shoot
- area of leaves
- tree height
- area of top projection
- top drying percentage
- leaf color
- damage caused by pests and diseases.

Table 23 contains distribution of small-leaved linden by categories of state in the streets with high intensity of transport flows (Schelkovskoye Shausse).

Table 23. Distribution of Small-Leaved Linden by Categories of State in the Streets with High Intensity of Transport Flows in 1999

Street Name	Number of accounted for trees, pieces	Distribution of trees by categories of state, pcs, ,%					
		0	1	2	3	4	5
Schelkovskoye Shausse	146	13.3	33.8	41.5	8.5	2.9	0

Note: 0 – without signs of weakening, 1 – weakening with less than 25% branch drying, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 – severely weakened with branch drying that ranges from 50% to 75%; 4 – drying trees with over 75% branch drying; 5 – dead wood of current year.

As is obvious from Table 23, only few trees in the streets along highways are healthy. In general, weakened trees prevail (over 70% of the total number of examined trees are weakened with less than 25% branch drying or moderately weakened, with branch drying that ranges from 25% to 50%).

To evaluate the state of trees in the streets of the city, we examined the above tree parameters. Interesting relationships that were found concern leaf area and length of last shoot.

4.4.2. Leaf area and tree condition.

The areas of many leaves were determined. The leaf area was measured by weighing, assuming a constant leaf thickness. An example of thus obtained values of leaf areas of one item is given in Table 24.

Table 24. Leaf Area of Trees (item No. 6, 1999)

Leaf number	Leaf area, cm^2 , six trees					
	1	**2**	**3**	**4**	**5**	**6**
1	29,75	27,80	35,12	38,58	23,56	19,15
2	18,26	30,98	36,34	27,68	22,97	23,56
3	28,28	31,71	23,30	28,27	27,98	17,67
4	31,52	34,39	22,92	20,91	20,02	23,32
5	21,50	20,98	22,93	40,64	24,15	15,02
6	20,03	34,88	21,46	29,45	20,02	14,73
7	28,28	25,12	24,39	25,92	19,73	20,02
8	27,09	27,07	24,31	26,50	17,67	11,49
9	27,68	36,58	24,53	34,46	26,80	11,78
10	22,97	31,22	22,92	37,99	17,08	20,02
11	26,21	33,41	20,00	39,47	19,73	13,84
12	20,62	22,44	20,00	39,46	25,04	14,43
13	25,63	38,09	23,90	30,63	17,67	15,61
14	35,05	25,85	19,26	35,34	24,44	18,85
15	27,39	30,97	24,87	22,38	21,79	20,61
16	27,68	20,24	24,85	23,56	20,62	20,68
17	39,17	31,71	23,65	35,34	23,26	21,50
18	29,75	34,15	23,65	27,68	25,92	22,69
19	31,52	25,61	23,80	36,22	16,78	11,78
20	28,57	35,12	23,17	20,91	20,32	18,85
21	20,61	35,61	26,09	20,02	25,33	15,31
22	22,68	32,44	26,48	25,39	17,96	15,61

23	17,97	29,76	26,53	35,93	26,80	18,85
24	39,17	30,24	20,87	30,92	29,16	24,15
25	33,58	23,17	26,82	27,68	23,86	25,04
26	32,99	27,56	33,17	27,04	20,32	20,03
27	25,04	30,98	25,60	30,04	23,27	20,32
28	42,71	38,78	20,97	22,09	18,85	19,14
29	25,04	33,66	26,58	39,76	16,50	19,44
30	31,81	21,46	19,02	20,32	16,78	20,32
31	22,68	26,34	26,34	35,64	17,96	17,96
32	23,56	36,10	19,26	27,68	18,85	21,50
33	41,24	39,77	18,78	38,38	25,04	13,55
34	20,91	36,10	18,78	34,75	26,80	14,43
35	23,56	37,57	32,92	29,74	28,28	20,03
36	21,50	33,66	26,58	41,82	25,92	17,67
37	33,87	21,95	27,31	29,45	20,03	24,15
38	45,94	18,78	38,29	19,73	20,02	17,08
39	18,85	20,24	32,43	18,55	19,44	24,15
40	44,77	28,78	30,78	21,50	18,55	18,56
41	41,24	33,41	39,02	39,17	17,08	12,96
42	39,76	29,51	27,31	33,28	20,32	17,97
43	38,43	37,07	27,42	35,93	16,49	22,68
44	26,21	24,39	34,87	28,78	16,20	16,20
45	38,29	22,19	38,01	41,22	17,08	26,21
46	32,69	30,98	22,19	29,02	16,20	15,32
47	28,27	21,46	17,31	36,83	16,20	21,76
48	58,61	23,90	26,82	22,19	18,55	24,44
49	35,34	29,76	29,51	20,48	17,37	12,37
50	20,32	18,78	23,17	34,39	20,61	16,49
51	35,64	25,85	31,21	34,63	23,56	20,91
52	28,27	24,15	37,56	31,46	18,26	18,26
53	20,32	37,80	30,73	37,32	16,76	22,39
54	23,56	19,76	21,46	18,29	17,37	23,27
55	20,02	35,36	20,48	18,78	23,85	19,73
56	25,03	40,00	37,07	39,02	18,55	12,96
57	39,76	26,58	22,43	24,88	18,55	24,15
58	29,45	23,66	38,78	25,85	25,03	15,32
59	33,57	23,90	33,65	29,27	24,74	13,84
60	21,79	26,10	35,36	28,05	18,85	15,02
61	21,20	34,88	38,04	37,80	19,14	23,56
62	26,21	20,98	31,46	19,27	16,20	25,62
63	21,20	18,54	34,14	31,71	19,44	20,91
64	14,72	20,98	23,41	20,73	17,96	22,68
65	26,21	31,22	34,63	29,27	22,09	22,68
66	22,97	22,68	26,39	28,05	20,32	14,14
67	28,57	30,73	30,48	33,66	26,21	14,14
68	27,39	29,76	30,97	32,93	22,68	15,02
69	20,32	26,52	32,00	38,29	18,26	16,79
70	27,98	21,65	32,00	29,45	22,09	20,91
71	20,32	31,47	36,00	39,47	16,78	19,15

72	38,58	25,49	36,12	36,82	22,00	12,96
73	35,49	34,82	35,42	28,27	26,53	25,62
74	18,55	39,51	36,74	31,11	20,11	26,21
75	27,09	26,44	32,17	38,00	25,88	26,51
76	22,68	26,00	31,16	37,00	23,16	24,00
77	32,98	36,55	32,54	38,50	22,50	24,10
78	22,97	36,74	27,09	35,53	18,17	16,84
79	24,44	33,50	17,50	35,72	23,84	12,16
80	35,64	38,52	22,32	34,23	22,56	25,07
81	23,26	22,00	24,18	23,57	22,59	24,43
82	19,44	24,93	39,53	25,07	20,75	25,62
83	19,44	21,65	26,32	20,14	25,23	15,50
84	17,08	30,12	35,84	28,42	16,87	12,96
85	30,33	30,52	36,53	27,53	23,00	13,72
86	24,44	22,54	28,27	18,97	17,60	13,69
87	18,55	22,47	29,05	32,21	23,00	13,80
88	18,55	33,54	34,66	38,50	23,50	19,00
89	27,39	21,00	31,53	37,58	24,00	18,00
90	31,81	22,50	34,72	35,36		18,56
91	17,37	22,14	33,00	35,63		26,10
92	39,98	38,52	27,40	34,52		26,00
93	25,62	33,51	18,34	35,00		
94	24,15	36,31	23,00	24,61		
95	31,22	40,00	23,47	26,19		
96	17,51	31,53	27,19	27,66		
97	22,60	26,72		28,76		
98	28,53	29,23		32,84		
99	27,31	39,00		34,82		
100	32,44	34,51		24,52		
101	17,65	34,63		24,23		
102	17,12	28,37		24,52		
103	23,11	28,42		25,10		
104	21,16	22,54		24,55		
105	34,67	26,17		19,34		
106	35,22	38,22		20,00		
107	25,78			20,83		
108	27,84			21,69		
109	36,19			19,75		
110	30,34			25,74		
111	35,23			25,00		
112	19,45					
113	28,24					
114	27,28					
115	23,54					
116	18,50					
117	22,50					
118	29,33					
119	21,32					
120	17,96					

121	19,50					
122	37,54					
123	19,42					
124	20,18					
125	27,43					
126	29,75					
127	35,51					
128	22,00					
129	21,00					
130	37,20					
131	39,40					
132	35,35					
133	28,60					
134	27,41					
135						
136						
average	27,59	29,28	28,09	29,78	21,12	19,04

As is obvious from Table 24 and Fig. 30, the values of leaf area of trees have a fairly great variation from its average value.

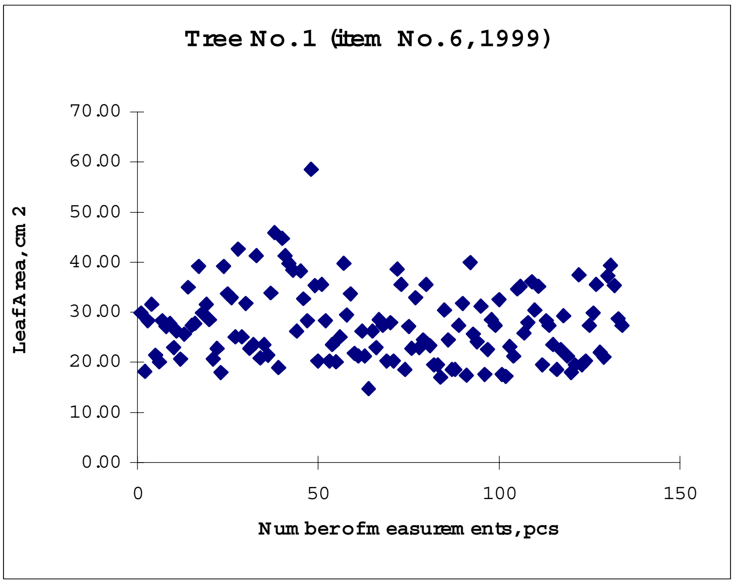

Fig. 30. Example of leaf area of a severely weakened tree (with branch drying that ranges from 50% to 75%), 1999 data (actual values).

For instance, for tree No. 1, the maximum value of the leaf area is equal to 58.61 cm^2, whereas the minimum one is 14.72 cm^2. These data are fairly difficult to compare, as a large experience error gives unreliable differences among trees in different state. Therefore, we classified all leaf areas of all trees into classes. Classes were chosen so that experience error inside each class was about 5% An example is given in Table 25. Such a Table is a frequency diagram with data columns having different lengths. Using a curve-fitting technique, a bell-shaped curve was fitted to the columns for each frequency diagram. The extreme value of such a bell-shaped curve may be considered as an approximation of the average value of leaf area of a tree. The approximated average values that are obtained in this way are presented in Table 26 for different tree states. This Table also presents the calculated exact average values of the measured areas (actual average values of leaf areas) for different tree states.

Table 25. Classes of Areas of Severely Weakened No. 1 (item No. 6, 1999)

Leaf Number	**Leaf Area, cm², classified**							
	10-15	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**40-45**	**45-50**
1	14,72	18,26	21,50	29,75	31,52	35,05	42,71	45,94
2		17,97	20,03	28,28	31,52	39,17	41,24	44,77
3		18,85	22,97	28,28	33,58	39,17	41,24	
4		18,55	20,62	27,09	32,99	39,76		
5		19,44	20,61	27,68	31,81	38,43		
6		19,44	22,68	26,21	33,87	38,29		
7		17,08	22,68	25,63	32,69	35,34		
8		18,55	23,56	27,39	33,57	35,64		
9		18,55	20,91	27,68	32,98	39,76		
10		17,37	23,56	29,75	30,33	38,58		
11		17,51	21,50	28,57	31,81	35,49		
12		17,65	20,02	25,04	31,22	35,64		
13		17,12	20,32	25,04	32,44	39,98		
14		19,45	20,32	26,21	34,67	35,22		
15		18,50	23,56	28,27	30,34	36,19		
16		17,96	21,76	28,27		35,23		
17		19,50	21,20	25,03		37,54		
18		19,42	21,20	29,45		35,51		
19			22,97	26,21		37,20		
20			20,32	26,21		39,40		
21			20,32	28,57		35,35		
22			22,68	27,39				
23			22,97	27,98				
24			24,44	27,09				
25			23,26	27,39				
26			24,44	25,62				
27			24,15	28,53				
28			22,60	27,31				
29			23,11	25,78				
30			21,16	27,84				
31			23,54	28,24				
32			22,50	27,28				
33			21,32	29,33				
34			20,18	27,43				
35			22,00	29,75				
36			21,00	28,60				
37				27,41				
Average	**14,72**	**18,40**	**22,00**	**27,50**	**32,36**	**37,24**	**41,73**	**45,36**
Standard deviation		**0,84**	**1,37**	**1,35**	**1,28**	**1,86**	**0,85**	**0,83**
Experience error		**5,00**	**6,00**	**4,90**	**4,00**	**5,00**	**2,1**	**2,0**

Table 26. Average Values of Leaf Areas in Trees in Different State

Tree State, Top Drying Percentage	Actual Average Values of Leaf Areas, cm2	Approximated Average Values of Leaf Areas, cm2
1999		
<25%	20,83	20,63
25 – 50%	33,31	34,73
50 – 75%	48,51	47,69
> 75%	27,95	29,10
2000		
<25%	21,9	20,6
25 – 50%	29,4	28,7
50 –75%	18,8	17,7
> 75%	15,2	15,9

As is obvious from Table 26, leaf area has a good correlation with tree state. It is to note the leaf areas of moderately and severely weakened trees with top drying that ranges from 25% to 75%). The leaf area of these trees has the maximum value. Side by side with further aggravation of tree state, the leaf area also declines, and strives to the minimum value in severely weakened trees with >75% branch drying. This statement is particularly well illustrated by the data in figures 31, 32, 33.

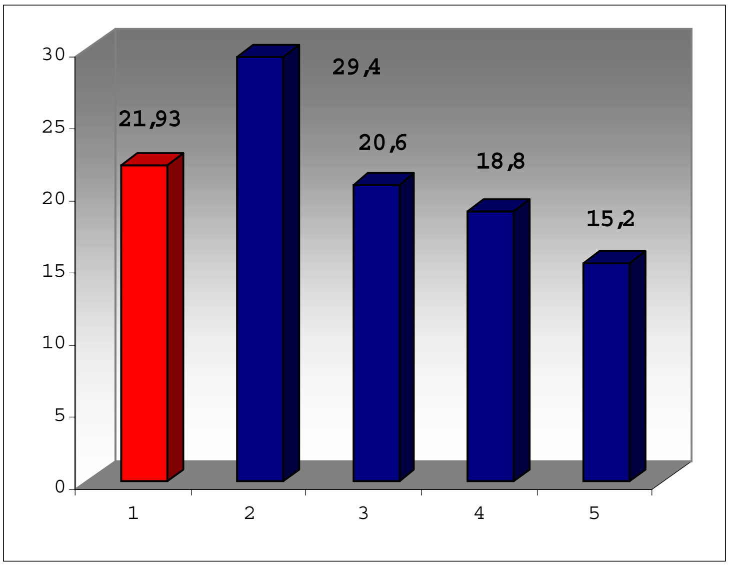

Fig. 31. Leaf area (cm^2) in trees in different state. 2000 data (actual values). 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3, 4 - severely

weakened trees with the percentage of branch drying that ranges from 50% to 75%; 5 – severely drying trees with branch drying over 75%.

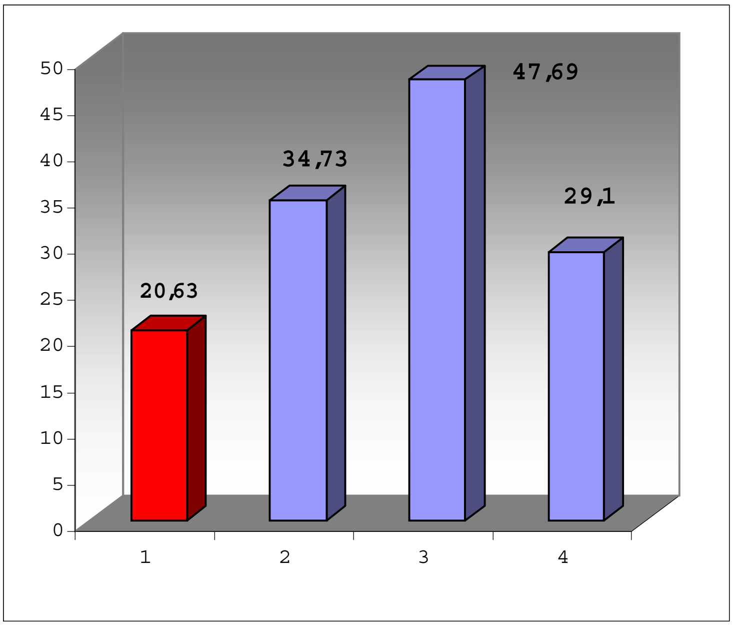

Fig. 32. Leaf area (cm^2) of trees in different state. 1999 data (approximated data): 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - severely weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – severely drying trees with branch drying over 75%.

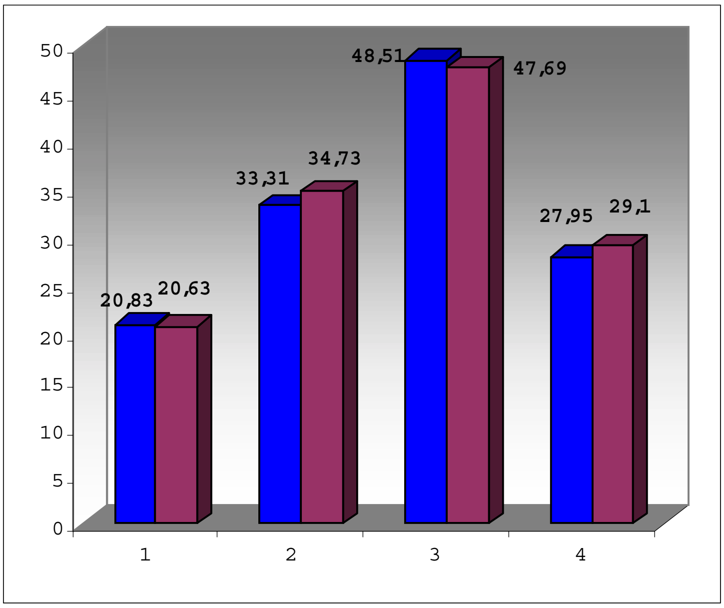

Fig. 33. Leaf area (cm^2) of trees in different state. 1999 data Actual(left columns) and approximated (right columns) values: 1 – moderately weakened trees with branch drying of less than 25%, 2 – moderately weakened trees with branch drying that ranges from 25% to 50%; 3 - severely weakened trees with the percentage of branch drying that ranges from 50% to 75%; 4 – severelly drying trees with branch drying over 75%.

4.4.3. Last Shoot length and tree condition.

Length of the last shoot, which we also determined for all examined trees in 2000, is a fairly good diagnostic sign of the tree state. The results of our research are given in Table 27.

Table 27. Average Values of Last Shoot Length of Trees in Different State

Tree State, Branch Drying Percentage	Last Shoot Length, cm	Experience error,%
<25%	12,7	4,8
25 – 50%	12,4	3,2
50 –75%	4,6	3,9
> 75%	5,7	2,7

As is obvious from the Table 25 data, there is a rather close connection between the tree state and the last shoot length: the better the tree state the longer the last shoot; the more depressed the tree the shorter the last shoot.

5. CONCLUSION

As a result of our research, the following conclusions can be made:

1. As the soil humidity plays a decisive role in the life of plants and is their life basis, there must be a close relationship between the tree state and the moisture content in the soil. For instance, the minimum soil humidity is observed under trees in very poor state. Moisture content in the soils under trees in a relatively satisfactory state in almost twice as high.
2. Our data show that the leaf drying rate slows down in the soils subject to drying. Good correlation was obtained between the drying (withering) rate of the leaf and the tree state. The maximum water quantity in leaf cells preserves the tree growing in favorable environment – in the forest clearing, and a leaf of this tree retains maximum moisture 5-6 hours after its cutting. Moisture content in leaves and leaf drying rate after its cutting have somewhat different dependencies for trees growing in the town, i.e. in more difficult environment. A fairly clear-cut relationship may be traced between the tree status and the leaf drying rate. It is to note that practically all examined trees in town experience water stress. The worse the water stress is, the worse the tree state is. Severely weakened trees (over 75% of branch drying) vs. trees in better state experience the highest water stress. Water content in leaves immediately after leaf cutting in these trees is minimum. Accordingly, the leaf drying rate in these trees is also minimum. Mildly weakened trees (up to 25% of leaf drying) in satisfactory state in town vs. other urban plants have the highest moisture content in leaves at the initial observation point and 5-6 hours after leaf cutting. However, it is much lower than in trees growing in their motherland, in the forest clearing, in the natural soil conditions. Moderately weakened trees (40% of branch drying) occupy an intermediate position. On the one hand, they contain a fairly low moisture content during leaf cutting.

Moisture content in leaves, in this case, is comparable with moisture content in trees in the best state in town. On the other hand, in 5-6 hours the moisture content in leaves is approximated to those in the trees with a very poor state. Therefore, one can suppose that moderately weakened trees, with up to 50% of top drying on average, after necessary watering, can recover their lost turgor of cells and gradually increase their decorative value. Severely weakened trees, with more than 50% of top drying, are obviously unable to recover their lost turgor of cells and their decorative properties.

3. As is known, full moisture reserve in soil takes shape subject to its optimum water and physical properties. One of its most important properties are granulometric composition and soil structure. Following the results of our research of granulometric composition, urban soil contains a fairly high quantity of dust fraction, in particular under trees in poor state. For instance, soil under trees with 75% of top drying contains 28% of particles of less than 0.02 mm, and under mildly weakened trees, 8-10%.

   As is known, dust possesses fairly negative water and physical properties. For instance, large dust fraction possesses some physical properties of sand: it is not plastic, does not swell easily, possesses low water permeability. Medium dust is characterized by high content of mica lending the fraction high plasticity and cohesion. Medium dust, as more dispersive, holds moisture better but has low water permeability, is unable to coagulate, does not participate in structure formation and physical and chemical processes that take place in the soil. Therefore, the soils we have examined, being enriched by a fraction of large and medium dust, are easily transformed in dust, tend to bloating and compression, and are distinguished by low water permeability. Small dust is characterized by relatively high dispersion, consists of primary and secondary minerals. In connection with the above, it possesses a number of properties that are untypical of large fractions: it is able to coagulate and form structure, possesses a good absorption capacity, contains high quantity of humus substances. However, exuberance of small dust in soils in free, non-aggregate state lends such unfavorable properties to soils as low water permeability, high quantity of unavailable water, high swelling capacity and compression, stickiness, fissuring, and dense structure.

4. Therefore, it is the structure nature that mostly determines physical conditions in soil, its water / air/ thermal regimes and, consequently, life conditions for plants and micro-flora. Structured soil is much easier penetrated by air and water than dusty soil, it has a better moisture capacity and evaporates less water, specific resistance in handling is lower on structured soil, it is easier to penetrate for plant roots, it is easier to combat drought and erosion on structured soils. As is known, micro-aggregates of 0.25-7(10) mm that possess high porosity (>45%), mechanical durability and water permeability have the highest agronomical value. Structured soil is the soil that contains over 55% (according to several data, 80%) of water durable aggregates of 0.25-7(10) mm. When agronomically valuable structure is available in soil, optimum physical properties are created – porosity, dense structure, water / air/ heat/ pH / micro-biological and nutrient regimes as well as physical and mechanical properties – cohesion, specific resistance, crust formation, etc.

   Our findings testify to high dustiness of urban soils, in particular under trees in very poor state. For instance, soil under these trees contains over 70% of aggregates of less than 0.5 mm (of the total number of agronomically valuable aggregates). The picture is slightly better in soils under mildly or moderately weakened trees. The number of aggregates of less than 0.5 mm is equal to 40% and 50% respectively, which also does not conform to their optimum content. Therefore, one can suppose that examined soils mostly consist of primary particles and micro-aggregates, i.e. they are unstructured. Mechanical elements lie compactly in unstructured soil, so mostly capillary pores are found in it. In this connection, water is absorbed very slowly in unstructured soils, its bulk may be lost due to surface drainage. A dense capillary network in the depth of unstructured soil also leads to great losses of moisture due to evaporation.

5. According to our data, soils along highways under plantations in very poor state (>70% of branch drying) have fairly low fertility: the content of mobile potassium and phosphorus, and the humus content are, are a rule, low. The content of calcium and magnesium cations is also low.

   Soils under plantations in satisfactory (up to 25% of branch drying) and relatively satisfactory (40% of branch drying) state have better fertility. These soils are fairly well provided with biologically active elements – phosphorus and potassium. High content of potassium and phosphorus may result from use of fertilizers and household pollution of plant habitats within a narrow lawn stripe along highways. It is to note a relatively high content of calcium and magnesium cations in the absorbing complex of soils. Their high content in Moscow soils is explained by many authors by the fact that calcium chlorides sprinkled on pavements and roads in winter fall into soil through surface drainage and drainage waters. Another reason is calcium release from various debris, construction rubbish, cement, bricks, etc. with alkaline medium due to acid precipitation.

   Our findings demonstrate the regularity that the content of mobile potassium and phosphorus surges under trees in relatively satisfactory state (40% of top drying). The content of these elements significantly drops under trees in very poor state (Fig. 2 and 3).

   As our findings show, there is no clear differentiation of acidity, humus, mobile micro-elements and heavy metals by layer (that would conform to natural differentiation, i.e. decrease with depth) in urban soils of highways. As a rule, absence or monotonous expression of regularities is typical to them due to the absence of genetic layers in these soils. Artificial layers, with different color and capacity, combine in soil layers, of which testify sharp changes and an even border between them. Construction and household rubbish are often found in the filling layers (brick crumbs, asphalt pieces, broken glass, coal, etc.), which is combined with the industrial waste, peat-compost mixture or the natural layer fragments.

6. SUMMARY

Moscow, the capital of Russia, is one of the world's largest cities. Its main part is 30 – 35 m above the Moskva river level. Generally, Moscow trees cannot benefit from capillary rise of groundwater. Average annual temperature is $+3.5^0$ C. The absolute minima and maxima are –48 and $+35^0$ C, respectively. Average annual precipitation is 575 – 600mm a year, from which 375 – 425mm falls in the warm period (April - October). The duration of the growing period is 151 days. The main parent rocks of the Moscow soils are: red-brown Dnieper moraine, cover clay and loam, fluvioglacial sands, ancient alluvial deposits. The following types of soils are formed from them: soddy-podzolic, soddy-podzolic half bogged soil, bogged soil. Soddy-podzolic soils prevail. The Moscow soils and subsoils are very intensively changed by antropogenic influences. E.g., construction activities for the Moscow underground transportation system reached down to 100m below the surface. A number of river parts were filled with soil or led through underground tubes.

In Moscow, street trees in pavements do occur, but the major part of the city trees are growing in grass (lawn, turf). Tree – grass combinations may be street line plantations, public gardens, boulevards, yard plantations, etc. Street line plantations are wide-spread. An analysis of the Moscow vegetation showed that the urban trees and shrubs are in a deep crisis. Tree condition is often very suboptimal. The state of street line plantations of small-leaved lime is the most unsatisfactory in comparison with other types of plantations. Generally, suboptimal conditions of urban vegetation may be caused by many factors. The thesis reports a study, for selected line plantations of *Tilia cordata* in Moscow, into the relations between visual estimate of tree condition, leaf evaporation, available water, type and amount of heavy metals, de-icing salt, available nutrients, pH.

Street line plantations of smal-leaved lime (*Tilia cordata*), which were situated in the North-East and East administrative "okrugs" (districts) of Moscow, were chosen as the objects of investigations. The eastern part of Moscow, the same as its centre, has the worst ecological indices. This territory is highly polluted with heavy metals, chloride contents and other toxic pollutants. The chosen objects of investigations were situated in two types of the city ecological conditions: in an ecologically unsuccessful zone (at the centre and some middle part of the city) and also in a relatively ecologically tense zone (in some middle part of the city and in the suburbs). A clearing in the forest in the localities near Moscow was chosen as an object for the absolute control. Lime plantations in the public garden in the suburbs of Moscow (in a zone of relatively successful conditions) served as objects for the relative control. There were totally seven main objects. Each object numbered (many) more than 6 trees.

Sample trees were chosen to determine the leaf transpiration (loss of water) in pre-set time intervals after the leaf has been teared off: every 3 minutes (up to 30 minutes) and every hour (up to 5-7 hours). Transpiration indices were determined by the weighing method. Leaves were chosen after the shoots had stopped growing (when the top leaf-bud was formed) from the middle part of the shoot on the southern side of the tree. Leaf fresh and oven-dry weights, leaf dimensions, and shoot lengths were also measured. Visual assessment of tree condition occurred through visual estimation of leaf drying (degree of withering). Leaf samples and soil samples were chemically analysed in order to diagnose the tree nutrient status, the heavy metals situation, and the de-icing salt threat. Soil samples were taken from the zones where the main root mass of the limes are located. Pedotransfer-functions were used to estimate water retention curves and available water holding capacity from organic matter content and grain size distribution.

The measured values of water loss of separated leaves were processed in order to obtain, for a measured tree, leaf drying rate (in mg water per mg dry matter per hour) as a function of time after leaves have been teared-off. It apeared that there is a connection between leaf drying and the measured transpiration. Actual evaporation of many trees is much less than potential evaporation. Although there is little known about the relation between tree ornamental value and water supply, the low evaporation values indicate that lack of water is at least one of the reasons of high leaf drying.

The values of available water holding capacity AWHC, estimated by the pedotransfer-functions, ranged from 0.167 to 0.294 (cm^3 cm^{-3}). We could not find a correlation between these values and leaf drying, probably because AWHC is only one of the factors that determine water supply. The average value is 0.197 . This value applies to soil samples from zones that were enriched with peat at tree planting. As mean soil quality of the entire root zone is likely less, we estimated the average AWHC of the tree root zones as ¾ of 0.197 = 0.15 . A simple, "average" water balance was established. This balance showed that, for Moscow trees, incidence of water stress is very likely.

Measured values of contents of many heavy metals in the leaves were compared with leaf drying. Interesting relations were found between contents of Cr, Br, Pb, Rb, Ni and leaf drying, if these contents were expressed as microgram per gram dry matter per cm^2 area of single leaf (single leaf area ranged between 10-40 cm^2). The values are higher than normal, which is likely caused by air pollution.

The Cl valus in the leaves were high and show a high correlation with leaf drying. It must be concluded that the application of de-icing salt during wintertime is an important cause of bad tree condition in Moscow. In addition, the Na-part has a negative influence on soil structure, and thus an indirect negative influence on tree condition. A further factor is that salt in soil water makes it more difficult for plants to take up water from the soil. A relation was found between tree shading and degree of tree damage by de-icing salt.

Very high amounts of dust fractions were found in the Moscow soils. This can, at least partly, be explained by bad soil structure and bad soil chemical properties. It causes sub-optimal soil physical properties.

The measuring data also showed relations between amount of leaf drying and leaf size and shoot length.

7. SAMENVATTING

Moskou, de hoofdstad van Rusland, is een van de grootste steden ter wereld. De hoogteligging is zodanig dat het stedelijk groen in het algemeen niet kan profiteren van het grondwater. De natuurlijke bodem is erg veranderd door anthropogene invloeden. Voorbeelden zijn de bouwactiviteiten voor de metro welke tot een diepte van 100m reikten, en het leiden van rivieren door ondergrondse buizenstelsels.

Moskou kent straatbomen in verharding, maar de meeste stadsbomen groeien in grasvelden of grasstroken. Veel voorkomend zijn bomenrijen in gras. De bomen van Moskou verkeren in een crisis-situatie. Vooral de veel voorkomende kleinbladige linde *(Tilia cordata)* vertoont op veel locaties een suboptimale conditie. Dit kan vele oorzaken hebben. Dit proefschrift handelt over een onderzoek aan rijen kleinbladige lindes in gras, waarin gezocht is naar relaties tussen: visuele beoordeling van boomconditie (mate van verdorring); bladgrootte; scheutlengte; bladverdamping; beschikbaar water in de bodem; zware metalen in de bodem; zware metalen in het blad; wegenstrooizout (zout in de bodem; zout in het blad); voedingsionen in de bodem; pH; vocht-toestand van de wortelzone; structuurtoestand van de wortelzone. Een groot deel van de metingen vond plaats tussen het hart van de stad (Kremlin) en een noordoostelijke voorstad (Schelkovo). Het onderzochte gebied heeft ongunstige ecologische condities. Er is gemeten in de jaren 1998, 1999 en 2000. Het veldwerk in 1998 had de funktie van het leren kennen van het boombestand van de stad en het leren hanteren van de meetmethodes. Dit laatste is vooral van belang voor de visuele schatting van de boomconditie, hetgeen een grote expertise vereist. Het proefschrift is gebaseerd op de meetcijfers uit 1999 en 2000. Blad- en scheutbemonsteringen vonden plaats in een bepaald groeistadium en uit een bepaald deel van de boomkroon.

De bladverdamping is gemeten aan afgesneden bladeren door periodiek wegen gedurende de eerste 30 minuten (frequent), en gedurende de eerste 5-7 uur (minder frequent) na afsnijden. De bodemvochtkarakteristieken van de groeilocaties zijn met z.g. pedotransfer-funkties geschat uit de korrelgrootte-verdeling en het gehalte aan organische stof. Hierbij is de z.g. Staring-reeks gebruikt.

De verdampingscijfers wezen op een vochttekort van de bomen. Er werd geen duidelijk verband gevonden tussen de boomconditie en het verloop van de bladverdamping gedurende de eerste 15 minuten na afsnijden. Het verdampingsverloop gedurende enkele uren na afsnijden toonde een veel betere relatie met boomconditie. De geschatte vochtkarakteristieken lieten geen verband zien met boomconditie. Dit is waarschijnlijk te wijten aan de onnauwkeurigheid die inherent is aan pedotransferfuncties. Een eenvoudige waterbalans bevestigde het vochttekort voor de begroeiing.

De bodemstructuur in de wortelzone's bleek verrassend slecht te zijn. Bij zeefanalyses werd veel stofachtig materiaal gevonden. Dit heeft veel oorzaken, zoals: negatieve invloed van strooizout, het vaak vergraven zijn, de imigratie van fijne delen uit sloopafval. De grote verschillen in bodemstructuur tussen stadsbodems en natuurlijke/landbouw-gronden is mondiaal zeer weinig onderzocht en verdient veel meer aandacht.

Er bleken relaties te zijn tussen de voedingstoestand van de bodem en boomconditie. De gehaltes aan zware metalen in het blad vertoonden een verband met de boomconditie indien deze gehaltes uitgedrukt zijn in ppm/cm^2 bladoppervlak. Deze verbanden vertoonden een optimum. Het bladoppervlak speelt een rol bij de invang van fijne delen. De chloorgehaltes in het blad waren hoog en duidelijk gecorreleerd aan boomconditie. Het gebruik van excessief veel strooizout in de winter is een belangrijke oorzaak van de slechte conditie van veel stadsbomen. De metingen lieten zien dat bomen aan de zonnige zijde van straten meer lijden onder de negatieve invloed van strooizout dan bomen aan de schaduwzijde. De bladgrootte als funktie van boomconditie vertoonde en optimum. Er zijn ook verbanden gevonden tussen boomconditie enerzijds en gehaltes aan voedingsionen, vochtgehalte in de wortelzone, en scheutlengte anderzijds.

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9. CURRICULUM VITAE

Olga Vasilevna Makarova was born on the 31th of March, 1968 in Mytischi, Moscow Region, Russia. In 1985, she finished High School and entered the Moscow Forestry Education Institute (Currently named Moscow State University of Forestry). She graduated in 1990 as a specialist in forest management and forest soils. In the early 90's she prepared within that University, as a post-graduate , a dissertation on the influence of logging on forest soils. On 26th of October, 1994, she defended her thesis: "The influence of logging on forest soil properties and early tree growth in the Moscow Region" in the Committee of Specialists of the Moscow State Forestry University. On the 3rd of March,1995, her academic degree of Candidate in the Agricultural Sciences has been confirmed by the National Presidium for Thesis Approvement. During November 1994 – April 1995, she was a guest worker at the Chair of Soil Technology in the Wageningen University in Wageningen, The Netherlands, and studied axial stress – strain relationships of fine roots of Beech and Larch in loading to failure and in cyclic loading. In 1995, she obtained a fellowship from the Wageningen University for preparation of a PhD-thesis within the Chair of Soil Technology of that University. The involved measurements on city trees and soils were done in a number of streets in Moscow during a series of growing seasons.

Currently, she is associate professor within the Chair of Soil Science of the Moscow State Forestry University and Acting Head of that Chair. She participates in a joint project of The Netherlands Organization for Scientific Research NWO and the Russian Organization for Scientific Research RFBR on hydrometeorological aspects of problems of soil and vegetation in urbanized river systems. She is involved in the introduction of facilities for composting residues of urban trees and grass in Moscow, and in the introduction of high-quality substrates on the basis of peat products in the Moscow Region.

She is married and has a son.

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