Proc. Estonian Acad. Sci. Ecol., 1994, 4, 3, 118–127

https://doi.org/10.3176/ecol.1994.3.03

THE IMPACT OF EMISSION FROM A CEMENT PLANT ON FOREST LANDSCAPE

Erna ANNUKA

Institute of Ecology, Estonian Academy of Sciences, Kevade St. 2, EE-0001 Tallinn, Estonia

Presented by J. Martin

Received January 13, 1994; accepted June 1, 1994

Abstract. Changes in the macro- and microelement content and pH of gleyed sandy podzols and in the species composition of the forest floor under the influence of emission from a cement plant are discussed.

Key words: cement dust, chemical composition of soil, species composition of forest floor.

INTRODUCTION

The aerotechnogenic channel is one of the main channels through which the technogenic impact of industrial enterprises reaches wide surrounding areas causing structural changes in the landscape. The impact of the aerotechnogenic flow differs in the case of different industries and depends on the physico-chemical characteristics and density (intensity) of the flow. Changes in the landscape depend, in addition to the peculiarities of the aerotechnogenic flow, also on the load tolerance of the landscape concerned.

Below, we try to investigate the changes in some components of a landscape type in northern Estonia – the coastal plain. The field studies were carried out in 1991–93. The results are initial as only a few research data are available as yet.

MATERIALS AND METHODS

The starting point of the investigations was the so-called landscape principle according to which changes in individual components (soil, vegetation, water, air) are treated as interacting with one another. In studying the impact of the technogenic flow, this principle has been used mostly by representatives of the Moscow and Voronezh geographical schools (Дончева, 1978; Солнцева, 1981; Федотов, 1985; and others). These scholars also gave their reasons for using this approach.

On the basis of the landscape principle, we have detected the aerotechnogenic impact by comparing similar geographical complexes using the complex profile method and taking into account the intensity gradient of the aerotechnogenic flow. In order to compare the changes in the characteristics of geographical components, the technogenic index was used. This index, which characterizes the degree of changes, is calculated in relation to the corresponding parameters of the control plot.

Changes in the soil cover were registered on the basis of chemical analyses of soil samples. Special attention was paid to the soil pH and to related characteristics. Standard methods of soil analysis were used: the content of phosphorus and potassium was determined by the Egner–Riehm method, that of calcium and magnesium by the Egner–Riehm–Domingo method; pH was determined potentiometrically from KCl solution. The microelements were determined by wet mineralization in a solution of acids by the atomabsorption method.

The vegetation was characterized by the sample plot method. The plot area was 500 m^2 for the tree and shrub layer and 4 m^2 for the ground layer. The vitality of trees was assessed visually by a special method which took into account the number, colour, and length of needles and the length of shoots (Annuka & Rauk, 1982).

The complex profile on which the investigation plots are located lies in the east–west direction at the southern edge of the North-Estonian coastal plain (Fig. 1). The relief is flat and the territory lies 15–30 m above sea level. The bedrock of the area consists of Cambrian sandstone covered with Pleistocene and Holocene deposits with an average thickness of 50 m. The parent soil material consists of sands poor in carbonate. The soils are gleyed podzols. The sample plots are located in a coniferous forest where the dominant tree species is pine but also spruce occurs quite often. Birch and aspen can be found more rarely. The 75–90-year-old subject forest belongs to the *Oxalis-Myrtillus* subtype.

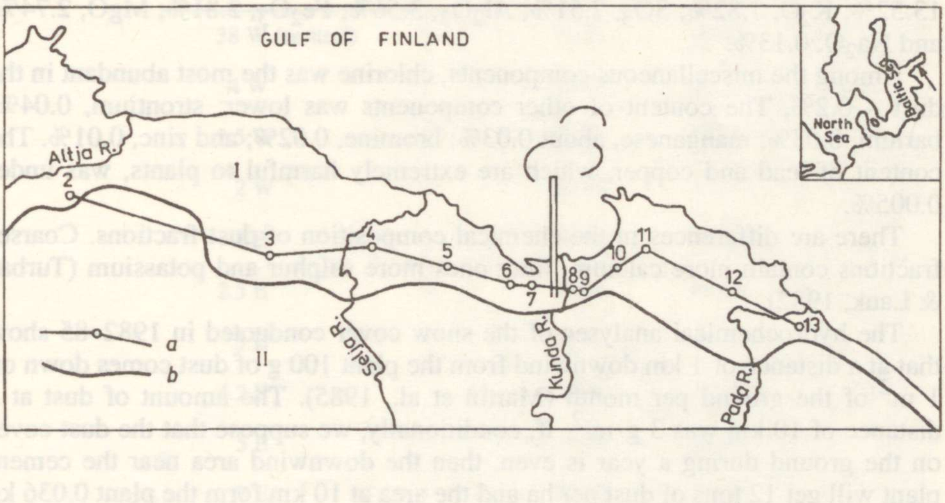

Fig.1. Location of investigation plots. Landscape regions (according to Kildema, 1969): I, North-Estonian coastal plain ; II, Northeast-Estonian plateau.
a, number of the investigation plot on the landscape profile; plot 1, the control, is not shown;
b, border of the landscape regions.

The annual amount of precipitation in the surroundings of the profile is 560–575 mm, which is about the average of Estonia. The amount of precipitation during colder seasons (November–March) is 150–180 mm, during warmer seasons (April–October) 380–410 mm. The dominating winds blow from the south throughout the year though during the warmer seasons winds from the west are also frequent. Taking into account the direction of winds, it would have been more appropriate to locate the complex profile more in the southwest–northeast or north–south directions but the landscape structure of the territory did not allow us to do that. The coastal plain rich in forests spreads as a 2–5 km west–eastern belt, bordering on a limestone plateau barely covered with trees in the south and the Gulf of Finland in the north (Fig. 1). The profile extends 38 km to the west and 12 km to the east from a cement plant. The control plot was situated in the westernmost part of the profile, not shown in Fig. 1. There were thirteen main investigation plots and eight auxiliary plots (short-term investigations). It was not possible to extend the profile to the east as there it would have overlapped the impact zone of the oil-shale industry. Thus, it was not possible to determine the extent of the downwind impact of the aerotechnogenic flow from the cement plant.

CHARACTERISTICS OF THE AEROTECHNOGENIC FLOW

The aerotechnogenic flow comes from a cement plant situated at the eastern border of Kunda, a small provincial town in Estonia. The plant has been operating since 1871. At first, it worked at a low capacity, but the production was expanded in the 1960s. In the 1970s the output reached a million tons per year. During the past twenty years, the dust load in the vicinity of the plant has been very high: 98 900 t in 1991. In addition, 6400 t SO_2, 1000 t NO_x, and 700 t CO were emitted into the air each year (Estonian Environment, 1991). The content of dust is characterized as follows (Turbas & Hiis, 1969): CaO, 42.48%; SiO_2, 13.52%; K_2O, 7.82%; SO_3, 7.51%; Al_2O_3, 3.56%; Fe_2O_3, 2.81%; MgO, 2.74%; and Na_2O, 0.13%.

Among the miscellaneous components, chlorine was the most abundant in the dust – 0.2%. The content of other components was lower: strontium, 0.04%; barium, 0.03%; manganese, about 0.03%; bromine, 0.02%; and zinc, 0.01%. The content of lead and copper, which are extremely harmful to plants, was under 0.005%.

There are differences in the chemical composition of dust fractions. Coarser fractions contain more calcium, finer ones more sulphur and potassium (Turbas & Lauk, 1982).

The hydrochemical analyses of the snow cover conducted in 1982–85 show that at a distance of 1 km downwind from the plant 100 g of dust comes down on 1 m^2 of the ground per month (Martin et al., 1985). The amount of dust at a distance of 10 km was 3 $g \cdot m^{-2}$. If, conditionally, we suppose that the dust cover on the ground during a year is even, then the downwind area near the cement plant will get 12 tons of dust per ha and the area at 10 km form the plant 0.036 kg per ha.

RESULTS

A comparative visual observation of the investigation plots showed that near the plant great amounts of dust occurred on the plants and tree leaves, trunks, and branches as well as on the ground. The litter layer had become mixed with dust and was grey. At a growing distance from the plant, there was less visible dust.

However, the impact of the technogenic load was revealed by physico-chemical peculiarities of landscape components up to 15 km from the plant.

Changes in the soil cover. The technogenic flow has the strongest impact on upper soil horizons, especially litter and humus horizons. These layers operate as effective filters towards deeper horizons but lose their initial properties in the process. The litter layer in the vicinity of the plant is characterized by a high ash content and a low content of organic matter. While in natural forest soil (the control plot) there was 11% of ash elements in the upper part of the litter layer at a depth of 0–2 cm and 30% at a depth of 3–7 cm, then the corresponding figures at 2 km to the east of the plant were 74 and 61 (Table 1). In a natural complex, the amount of organic matter is greater in the upper part of the litter layer and lower in its deeper part. The situation is quite the opposite on a territory of a high dust load. This is caused, on the one hand, by a continuous influx of mineral dust by the air and, on the other, by a lower generation of organic matter due to decreased bioproduction as a result of the high dust load. Quicker destruction of organic matter in a carbonate environment is also possible.

Table 1

Ash content in the litter layer of the research plots, %

Distance (km) and direction from the pollution source	Depth	
	0–2 cm	3–7 cm
38 W (control)	11.51	30.18
4 W	20.35	38.03
2.5 W	20.68	60.96
2 W	39.93	61.21
2 E	74.28	61.27
2.5 E	63.14	61.18
3 E	61.6	62.77
4.2 E	30.58	51.31
5 E	39.82	40.74
7 E	35.53	41.35
10 E	29.81	30.48

The content of all the main components of the aerotechnogenic flow is high near the plant. Their concentration to the east of the plant is more than twice as high as to the west because of the predominating direction of winds. The contrast with the control is especially noticeable in the content of calcium and magnesium (Fig. 2). The content of sodium is extremely high in the litter layer near the plant. Farther from the plant the content of all these elements decreases quickly; for example, at a distance of 5 km to the east the concentration is already twice lower. To the west of the plant, the content of the same elements is 2–3 times lower than in the eastern plots.

The distribution of the potassium content in the impact zone of the technogenic flow is more even (Fig. 2) and there is not such overabundance near the plant as in case of Ca and Mg. In comparison with the control, the content of potassium in the litter layer is not more than four times higher, while the content of calcium and magnesium may be 15–17 times and that of sodium 30 times higher than the control.

The sulphur content has risen noticeably only in the upper part of the litter horizon in the nearest vicinity of the pollution source, i.e. up to 3 km downwind from the plant. The technogenity index of sulphur is 3.9 there. A rise in the phosphorus content can be noticed also only in a narrow area near the plant. However, it is much weaker than the sulphur anomaly: the technogenity index is 2.2.

The content of several heavy metals found in cement dust has also risen in the litter layer. Lead and cadmium show the most noticeable increase. The maximum technogenity index for these elements in the upper part of the litter layer is 6. The content of copper has risen 2.5 times, that of manganese 2.2 times.

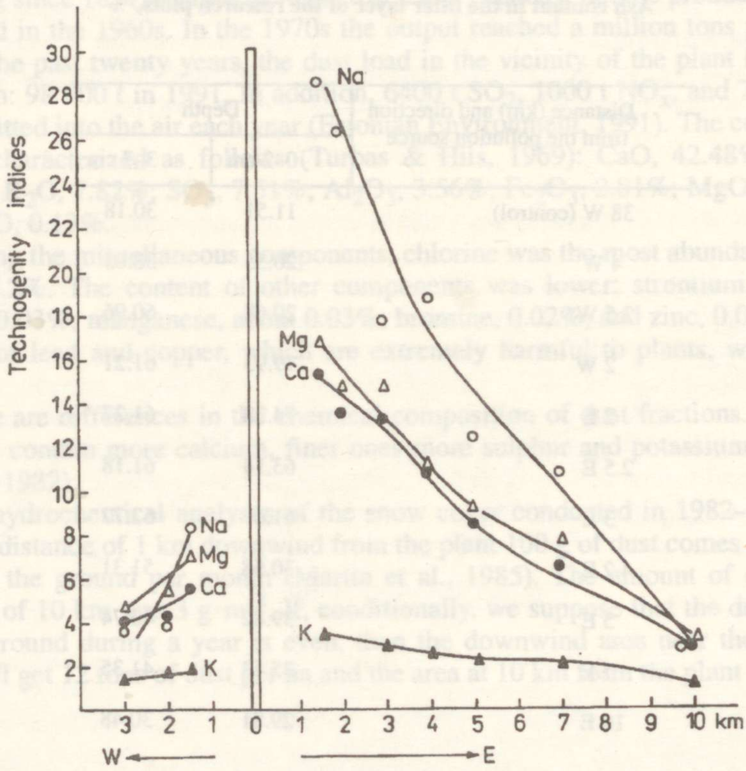

Fig. 2. Changes in the content of calcium, magnesium, sodium, and potassium in the forest litter layer due to the impact of the aerotechnogenic flow from the cement plant. The technogenity indices were calculated in relation to the control plots located at 38 km to the west of the plant.

According to the literature (Dubińska, 1982), there occurs also a considerable rise in the strontium and barium content in the vicinity of cement plants. No data on their content are available from the Kunda region, but considering their content in dust (strontium, 400 $g \cdot t^{-1}$; barium, 322 $g \cdot t^{-1}$), their increased content in soil could be expected.

The research showed that the impact of the aerotechnogenic flow decreased towards the depth together with the falling intensity of the flow (Fig. 3). At a distance of 2 km from the plant an abnormally high concentration of Ca and Mg can be observed down to a depth of 70 cm. At a distance of 5 km the content of these elements normalizes at a depth of 30 cm on the average.

The flow of such large amounts of calcium, magnesium, potassium, and sodium into the soil has caused changes in its sorption complex. The total amount of bases in the litter and humus horizons has risen 3–10 times in comparison with the control. The hydrolytic acidity has decreased. The saturation degree has become very high, reaching 99% in the litter layer of the impact zone of the maximum technogenic flow and 75–85% in deeper horizons. These changes are accompanied by a great increase in the pH value. The pH of the litter layer is up to 7.8 and it tends to be high down to a depth of 50 cm in the areas of a high technogenic load. In the horizontal direction, a rise in the pH value is noticeable in the upper soil horizons up to a distance of 10 km to the east of the pollution source. At this distance the pH value exceeds that of the control by one unit.

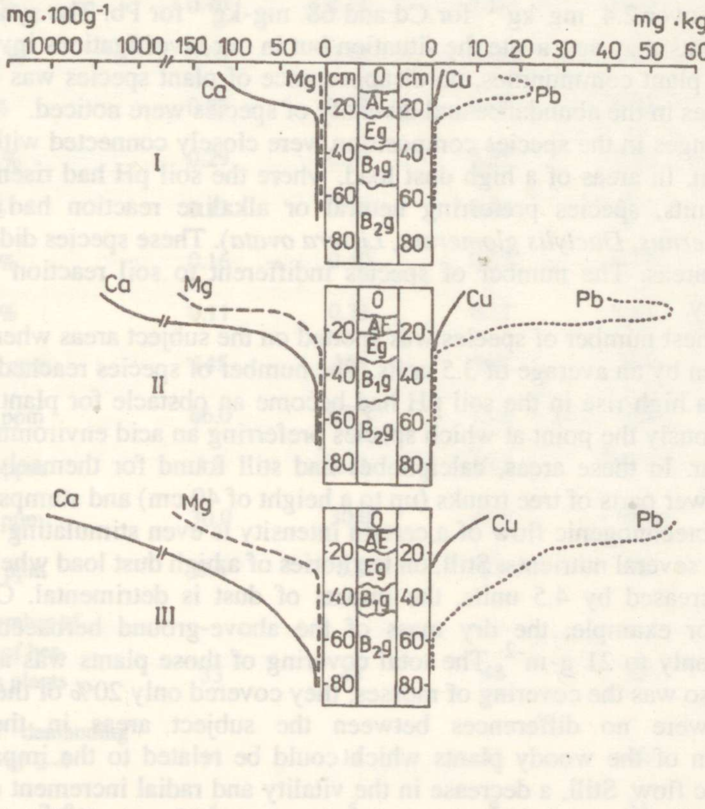

Fig. 3. Vertical distribution of the concentration of some chemical elements in soil: I, 38 km to the west of the cement plant (control); II, 5 km to the east; and III, 2 km to the east of the cement plant.

In a natural podzol the forest litter layer pH is lower than that of the mineral horizon below it. The opposite situation indicates a technogenic change in the soil. An increase in the pH value of the litter layer is considered to be the criterion of alkalization of podzols (Kokk, 1988). Thus, the subject territory can be characterized as undergoing forest soil alkalization, which varies from barely noticeable to strong depending on the dust load. A similar effect of cement dust has been determined in various investigations, also experimentally (Dubińska, 1982; Greszta, 1988; Greszta et al., 1988). The impact of cement dust in increasing the soil pH has also been proved by experiments carried out with dust on Estonian agricultural fields (Hallik, 1965; Turbas & Lauk, 1982). Investigators engaged in soil mapping have noticed increased soil pH in wide areas in the whole North-East Estonia. The cause is ash emitted by oil-shale-fired power plants in the east and cement dust in the west. Alkalization is the strongest near Kunda (Teras, 1984; Kokk, 1988).

Changes in the plant cover. Considering the chemical composition of cement dust and the changes occurring in the soil due to dust impact, the aerotechnogenic flow should not cause lethal damage to plants. The most toxic elements for plants in the cement dust are cadmium and lead. The dangerous concentration of cadmium in soil should be over 500 $mg \cdot kg^{-1}$ and that of lead 1000 $mg \cdot kg^{-1}$ (Kloke & Schenke, 1973; Kloke, 1975). On the subject territory, the content of Cd and Pb in the upper soil horizon has risen in comparison with the control, but is still not over 2.4 $mg \cdot kg^{-1}$ for Cd and 68 $mg \cdot kg^{-1}$ for Pb. The synergism of toxic elements may aggravate the situation but in our investigations involving an analysis of plant communities, no disappearance of plant species was observed. Still, changes in the abundance and diversity of species were noticed.

The changes in the species composition were closely connected with those in soil reaction. In areas of a high dust load, where the soil pH had risen by more than 3.5 units, species preferring neutral or alkaline reaction had appeared (*Lathyrus vernus*, *Dactylis glomerata*, *Listera ovata*). These species did not grow in control areas. The number of species indifferent to soil reaction had risen considerably.

The highest number of species was spotted on the subject areas where the soil pH had risen by an average of 3.5 units. The number of species reached 65 there. Still, such a high rise in the soil pH had become an obstacle for plant intrusion and is obviously the point at which species preferring an acid environment begin to disappear. In these areas, calciphobes had still found for themselves a safe niche on lower parts of tree trunks (up to a height of 40 cm) and stumps.

The aerotechnogenic flow of a certain intensity is even stimulating for plants as it carries several nutrients. Still, on territories of a high dust load where the soil pH has increased by 4.5 units, the impact of dust is detrimental. On such a territory, for example, the dry mass of the above-ground herbaceous plants amounted only to 21 $g \cdot m^{-2}$. The total covering of those plants was also low – 40%. And so was the covering of mosses: they covered only 20% of the ground.

There were no differences between the subject areas in the species composition of the woody plants which could be related to the impact of the technogenic flow. Still, a decrease in the vitality and radial increment of trees, a thinning of needles, and great variations in needle length were observed (Annuka & Rauk, 1992). These changes were noticeable up to a distance of 3 km to the west and up to 6–7 km to the east from the plant. Up to 3 km to the east, the decrease in the radial increment was 40% in comparison with the control.

Table 2

Characterization of landscape components in the impact zones of the cement plant

Characteristic	Impact zone, its distance to, and direction from the plant				
	I	II	III	IV	V
	>15 km W	5–15 km W 10 km E	2–5 km W 5–10 km E	0.5–2 km W 2–5 km E	<0.5 km W <2 km E
Soil pH in horizon O	2.7–3.4	4.0–4.5	5.5–6.5	6.8–7.0	7.5–8.5
E	3.5–3.8	3.4–4.2	5.7–6.0	5.8–6.5	7.1–7.3
B	3.8–4.4	3.8–4.6	3.8–5.0	4.3–5.5	5.1–5.7
Litter horizon:					
Hydrol. aci., mg equiv. per 100 g	48.2–87.1	19.7–50.2	2.2–46.7	8.1–19.8	0.0
Saturation degree, %	8.0	42.0	99.2	99.6	99.4
Ca, %	0.70	2.13	5.32	9.16	12.97
Mg, %	0.08	0.18	0.68	1.03	1.3
K, %	0.25	0.25	0.58	0.78	1.15
Na, %	0.29	0.79	2.37	5.75	9.25
S, %	0.13	0.14	0.16	0.23	0.34
Al, %	0.16	0.40	0.52	0.79	0.85
Fe, %	0.11	0.33	0.52	0.65	0.67
Mn, ppm	145	165	169	264	309
Zn, ppm	66.0	65.5	73.5	52.5	65.6
Cu, ppm	3.3	6.0	10.5	11.0	13.6
Pb, ppm	30.0	30.0	42.0	55.0	60.0
Cd, ppm	0.6	0.8	1.4	1.6	1.8
Total number of species of herbaceous plants	33	44	46	65	55
Species demanding soil pH of 2–4	11	11	11	12	10
7–8	4	5	8	11	14
Species indifferent to soil pH	12	14	17	26	21

As an intermediate stage of the research, summarized technogenity indices of the geocomplex were calculated on the basis of the technogenity indices reflecting the changes in the soil and plant cover. On their basis, five impact zones were distinguished: I, the area without technogenic impact; II, very slightly affected area; III, slightly affected area; IV, moderately affected area, and V, strongly affected area.

Some characteristic features of these zones are presented in Table 2. In zones IV and V, changes in the soil profile have reached even the illuvial horizon. The soil is strongly alkalized. The soil pH has risen in the upper horizons by more than 3.5 units. The geographical complex has lost its initial characteristic features. In the case of these zones the type of the geographical complex has changed due to the impact of the technogenic flow.

CONCLUSIONS

The following should be pointed out about the impact of the technogenic flow from the cement plant on landscape components:

1. Cement dust affects the soil cover strongly towards alkalization, increasing the pH of the sandy podzols of the forest landscape by up to 4.5 units.
2. The total content of the bases in soils has risen sharply; hydrolytic acidity has dropped very low. The saturation degree reaches 99% in highly affected zones.
3. The technogenic impact is the strongest in the litter layer, decreasing towards the depth of the soil. In the areas of a strong impact, the effect is noticeable down to 70 cm.
4. In the horizontal direction, a strong technogenic impact is observed up to a distance of 5 km downwind and up to 3 km upwind; a slight impact is noticeable up to 15 km upwind.
5. The aerotechnogenic flow has not excluded species from the plant cover, but in the areas of a high dust load the abundance of typical forest species has fallen, especially of those with roots near the surface.
6. In the areas of a high dust load, several species of high pH demand have appeared in the ground layer due to the shift of soil reaction towards alkalization.
7. In the areas where the soil pH has risen by at least 3.5 units, the characteristic features of the initial geographical complex have been lost.

ACKNOWLEDGEMENTS

This research was supported by the Estonian Science Foundation. Thanks are due to M. Shestakov and Ü. Niinemets, who made the geobotanical analysis.

REFERENCES

Annuka, E., Rauk, J. 1982. Okaspuud tööstusmaastikus. – Eesti Loodus, 3, 155–159.

Annuka, E., Rauk, J. 1992. Tsemenditööstuse mõjust Kunda ümbruse mõnedele maastikukomponentidele. – Eesti Geograafia Seltsi aastaraamat, 27. Valgus, Tallinn, 68–79.

Dubińska, E. 1982. Wpływ przemysłu cementowego na gleby na przykładzie kombinatu cementowo-wapienniczego "Warta" w Działoszynie. – Zesz. nauk. AGH. Sòzologia i Sozotechnika, 14, 119–127.

Estonian Environment. 1991. Environmental Report 4. Helsinki.

Greszta, J. 1988. Effect of dusts from selected industrial plants on chemical properties of soils. – Scientific Papers of Krakow Agricultural Academy. Forestry, 18, 22–64.

Greszta, J., Nosek, A., Wąchalewski, T. 1988. Preliminary results of investigation on the effect of different doses of dusts containing heavy metals on the dynamics of humus in forest environments. – Scientific Papers of Krakow Agricultural Academy. Forestry, 18, 65–87.

Hallik, O. 1965. Happeliste muldade lupjamine Eesti NSV-s. Eesti Raamat, Tallinn.

Kildema, K. 1969. Eesti NSV maastikulisest liigestusest. In: Maastike kujundamine Eesti NSV-s. Valgus, Tallinn, 5–20.

Kloke, A. 1975. Zur Anreichung von Cadmium in Böden und Pflanzen. – Sonderheft zur Zeitschrift "Landwirtschaftliche Forschung". Frankfurt am Main, 22, 200–206.

Kloke, A., Schenke, H. D. 1973. Quecksilber und Cadmium in Böden und Pflanzen. In: Kolloquium der Europäischen Gemeinschaften über Probleme im Zusammenhang mit der Kontamination des Menschen und seiner Umwelt durch Quecksilber und Cadmium, 48–62.

Kokk, R. 1988. Muldade leelistumine Kirde-Eestis. In: Eesti mullastik arvudes, 7. Riikliku Agrotööstuskomitee Info- ja Juurutusvalitsus, Tallinn, 87–93.

Martin, L., Utšvatov, V., Nilson, E., Martin, J., Geletjuk, N. 1985. Lumikatte geokeemiline uurimine ja lihhenoindikatsioon. In: Kaasaegse ökoloogia probleemid. Vabariikliku III ökoloogiakonverentsi teesid. Tartu, 11.–13. apr. 1985. Tartu, 87–89.

Teras, T. 1984. Kunda tsemenditehase tolmu mõjust Kunda ümbruse metsamuldadele. – Maakorraldus, 17. ENSV Põllumajandusministeeriumi Informatsiooni ja Juurutamise Valitsus, Tallinn, 11–22.

Turbas, E., Hiis, V. 1969. Pulverized lime fertilizers in the Estonian S.S.R., their effectiveness and application. – Transactions of Estonian Agricultural Academy, 62. Tartu, 101–115.

Turbas, E., Lauk, E. 1982. Lupjamisalase uurimistöö tulemustest ja soovitused muldade korduslupjamiseks. ENSV Põllumajandusministeeriumi Informatsiooni ja Juurutamise Valitsus, Tallinn.