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Air pollution impact on the crop production

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Abstract

This paper summarised results of research focused on the influence of air pollution on the crop production. Air quality influent crop production twice way: direct as results air pollution SO_2, NOx, SPM and O_3; indirect impact depend on the acid deposition, mainly wet deposition. We analysed space pattern of the concentrations of the basic air pollutant (SO_2, NOx, SPM, O_3) in three categories in terms of limits: without pollution, moderately polluted and strongly polluted and collected as number without dimension and wet deposition H^+, which showed acid deposition. Results of this analysis we synthesised in map with differentiation area of air pollution. Final synthesis direct and indirect impact we combined with buffering capacity of basic soil quality units in cadastral areas. Results of this method we provide as map, which showed regions with a discount (in percent) of the tax of agricultural soils. This map is interpretation output, which documented influence of pollution of the atmosphere and soils on the crop production.

Key words: air pollution, agricultural production, soil quality, agricultural tax

Introduction

The generation of evaluation system for air pollution impact upon agricultural production is caused by the state administration. State administration need to analyse, covering the whole area, damage caused by pollution and to extend a kind of compensation to the farmers in air polluted areas in the form of subsidies or agricultural tax allowance. The results of a study had drawn in this way were the basis for the regulation no. 279/97 Coll., which shows the way to calculate the agricultural tax allowance. In this paper we focus only on some aspects of the polluting substances impact on agriculture.

The anthropogenic proportion of many polluting substances origin is clear in the industrial time and has a global character. Some air pollutant concentration (e. g. sulphur dioxide, dust aerosol) decline in the Czech Republic in last ten years. This fact is a result of massive investments in desulphurization plants at the biggest sulphur dioxide stationary sources, investments in new technologies and also structural changes of our industry, especially the heavy and extractive industrial productivity decline. On the other hand, the concentrations of some other air polluting substances, e.g. nitrogen dioxide, show again a moderate increase, after the initial swift decrease in the first half of 1990s.

Number of air pollutants is enormous and we get, thanks to continually improving detection methods, a more complete picture of the earth's atmosphere pollution and of its impact on the living part of nature. But for practical aims we have to choose the substances whose data about concentrations or depositions are:

- in a sufficiently long measurement sequence,
- measured in the same way covering the whole area,
- interpolated with a sufficient precision covering the whole area of Czech Republic.

State of knowledge

The atmosphere polluted by some substances has a negative impact on both agricultural production and agricultural soil quality. In the Czech Republic so far a possible agricultural tax allowance has applied to the measured SO_2 concentration (there has been used an annual arithmetical mean calculated out of 24 hours concentrations of SO_2) in conformity with the regulation no. 613/1992 Coll. But even by then, synthetic papers of some Czech authors, e.g. Němec et al. (1992), Šimon (1990), evaluated also the other air pollutants, such as NOx, ozone, HF, CO_2 and heavy metals contained in aerosol. They point also at frequent synergistic action of the different pollutants and at precursor's function.

While a large group of published papers follows specific demonstrations of plant and soil defects caused by atmospheric substances (see below), there are only few synthetic papers that would follow the total damage evaluation concerning plant production or soil degradation. The main reason is a multi-factor impact of atmospheric pollutants on natural and cultured plant communities, reflecting into agricultural production profit decrease. The decrease is not only a result of lowered yields or soil fertility, but also a result of a lower production quality and secondarily produced inputs increasing the costs (e. g. liming, plant protection etc.).

The air quality affects agricultural production in a direct and an indirect ways.

Within the direct influence air pollutants affect the plants directly. The indirect influence means the impact of substances transported by wet or dry deposition into the soil (it is mainly the case of acid components of the atmospheric deposition and heavy metals) that often penetrate into plants through the soil. A big systematic problem still remains to be the research of different pollutants antagonistic, agonistic and synergic impact.

Direct influence of the pollutants

By the direct influence, stomata in leaves and needles are the gateway into the plants for gas components. The particles can block up stomata or collect on plant cuticle. Reaction of the plants against air pollutant influence depends mainly on light, temperature, CO_2 concentration, humidity and nutrients accessibility, vegetation period, etc. Some pollutants – SO_2, SPM, NO_2 and O_3 – may cause a visible damage to plant's leaves or needles, disturb their physiologic processes and reduce their growth. The NO2 impact on the plants becomes evident especially in combination with other compounds. The lowest concentrations by which an impact on plants was noticed do not show a big difference between natural vegetation and cultured plants. But with most natural vegetation communities a large nitrogen supply results in ruderalization, e.g. nitrofile varieties spreading.

The negative influence of air pollutants can develop with the agricultural crops by visible symptoms (chloroses, necroses), by a total fall in growth, yields decrease and quality loss. A looses in agricultural production, as a result of air pollution, are usually estimated by mathematics models. The results of laboratory and field experiments are used both as the input data of the models and for their verification (Heck 1989). Agricultural crops comprise many species (grain crops, fodder plants, fruit, vegetables, flowers) that can be used in miscellaneous ways. Dassler (1976) points out that air pollution (together with other stress factors) can cause crops production decrease or their market value reduction as a consequence of necrotic spots, dry matter content reduction, toxic substances accumulation in plant parts and product durability change. The greatest deal of papers focuses on production decrease as a consequence of air pollution with sulphur dioxide and ozone.

Agricultural crop's damage caused by sulphur dioxide was observed by some of the authors within many varieties (e. g. Loucks, Armentano 1982). According to Heck (1989), sulphur dioxide reduces the growth of plants, biomass, and consequently the yields. It is clover that belongs to the most sensitive varieties reacting to sulphur dioxide pollution. It was the first variety to disappear from grass communities on grasslands in areas with sulphur dioxide polluted air. Ozone affects clover in a similar way. Some sensitive clover varieties in Netherlands showed leaf damage already at the average concentration 5–28 $\mu g/m^3$ within an entire vegetation period and at the average daily concentration 16–80 $\mu g/m^3$. Yields decrease by up to 30% at a constant SO_2 impact has been observed with several crops. Some authors, e.g. Dassler (1976), Bugter, Tonneijck (1990) nevertheless describe an opposite effect, that is yields increase. Treshow (1970) says that the lucerne yields decrease, as a consequence of SO_2 impact, was directly proportional to the quantity of necrotic spots on the leaves. Growth reduction can happen also without visible damage. The extent of the damage to plants is subject to the pollutant concentration in the air, exposition length and other environmental factors including light, heat, relative humidity, CO_2 concentration, soil humidity and nutrition.

Relatively few data exist about dust aerosol (SPM) influence on agricultural crops. Dust aerosol produces a surface dust film on leaves and needles, which reduces falling solar radiation intensity, and consequently photosynthesis. Yields decrease can range from 5 to 10% and has been described in Germany in the area of Ruhr. Garber (1967) and Dassler (1976) say that the dust aerosol can have a negative effect on plants growth also by a toxic ingredient existence in the form of acids or heavy metals.

Nitrogen dioxide is the cause of growth reduction and visible damage. Treshow (1970) observed visible damages at the concentrations ranging from 4 to 20 $\mu g/m^3$.

But these high NO_2 concentrations in the open air are not presumable. According to Dempster and Manning (1988) research, a higher concentrations of NO_2 existence results in an increased plant perceptivity to parasites.

The agricultural crops damage caused by ozone has been described with many crops, and it develops usually in the limitation of growth and biomass production and in yields decrease. These effects can be, but not necessarily, accompanied by visible changes. Higher ozone concentrations also influence the interaction between plants and parasites (Mackenzie, El-Ashry 1989, Heck 1989). Yields decrease, visible changes on the plants and other ill effects have been described by many authors, including among others Bugter, Tonneijck 1990, Tonneijck 1994, Garber 1967, Dempster, Manning 1988, Fragmeier 1994, Scotti 1994, Younglove 1994, with many crops: tobacco plant, soya bean, beans, rye, wheat, potato, pumpkin, pea, lucerne and tomato. The correlation between leaf damage and yields decrease have been observed in field research, but only with the experiments projected specifically for this kind of observation (Tonneijck 1988, Heck 19890. Yields decrease was estimated for five agricultural crops varieties in the United States to 2–5% by a 12-hour average O_3 concentration 80 $\mu g/m^3$, to 6–21% by the concentration 120 $\mu g/m^3$ and to 15–40% by the concentration 160 $\mu g/m^3$ (Heck 1989). According to Fuhrer (1994) and Heck (1989), higher ozone concentrations can be the cause of a change in grasslands varieties composition. The abundance of some sensitive clover varieties is decreasing at the expense of less sensitive grass varieties. But clover does not constitute a fundamental component of pastures therefore these changes do not obviously mean yields and quality decrease.

Bugter, Tonneijck (1990), Treshow (1970), Heck (1989), Dempster, Manning (1980) say that some environmental factors, such as light, temperature, humidity etc. make the evaluation of plants sensitivity to ozone more difficult in field circumstances. Various plants and cultivars varieties response to ozone in different ways, therefore it is impossible to compare the results (Bugter, Tonneijck 1990). Neither it is possible to extrapolate yields decrease estimations in other localities or in other years on the basis of maximum ozone concentrations. This type of extrapolation is possible, according to Heck (1984), only on the basis of seasonal averages. Ozone threshold values for 8-hours concentrations and for a vegetation period reach approximately 65, respectively 50 $\mu g/m^3$. For shorter time intervals it is 400–800 $\mu g/m^3$ by 30-minutes concentrations, 180–400 $\mu g/m^3$ by 1-hour concentrations and 75–180 $\mu g/m^3$ by 4-hours concentrations (Guderian 1985). Another kind of pollutants, which often appears in combination with ozone (they develop from the same precursors) is peroxyacetylnitrates (PAN). Bunce (1991) mentions the toxic concentrations of ozone and PAN to be at 0.1 ppm. At this point the photosynthesis intensity already decreases two times. In the province of Ontario where a photochemical smog with higher ozone and PAN concentrations is frequent, the corn and white beans output falls down by 20 million CAD.

The development of the concentrations of monitored substances in the atmosphere, whose deposition on earth surface has acidifying influence, tends to be propitious in the last years. During last years the SO_2 emissions lowered considerably (in

1985–1997 by 69%), thanks to international agreements (United Nations ECE Convention), which we signed up to keep. Our enterprises – important SO_2 emitents – have started to come nearer, in their behaviour, to more economical and efficient OECD enterprises, equipped with better technologies for emissions elimination. Since the SO_2 emissions are being reduced in all neighbouring countries and the acid fallout are of a global – transferable – character, it is reflected in H^+ quantity, coming in dry or wet depositions into our soils. But since it is the wet deposition that plays a decisive role in the absolute quantity of acidifying substances infused into the soil or into an ecosystem. In fact means the annual quantity of precipitation, the distribution of hydrogen cations total deposition can considerably change from one year to another. This means the wet years accelerate acidification and debasification.

The study of critical loading for the landscape and its components is one of the privileged methods especially for the acidification effect findings. Several methodologies for this theme are available in the net and for their summary see for example Mausbach and Tugel (1997).

Indirect influence

The indirect influence means a initiated soils degradation and contamination, while its elimination leads to plant-growing costs increase or to land capability decrease. In every case the farming enterprise profitability comes down.

Soil degradation means the entire deterioration of physicochemical and biological soil character in comparison with original state where the mapping is more complicated than the ground cover mapping, since the original state of soil character in exactly localized points of the ground cover is missing. The critical loading by acid deposition depends mainly on the buffering capacity of the soil, which is proportional to the velocity of minerals chemical weathering and soil capability – its mineral equipment, pH, the dimension and saturation of soil absorption complex, humus quantity and quality – to neutralize acidity or more precisely superfluous hydrogen cations in soil solution – Tomášek (1985), Janderková (2000).

In order to assess soil and acid deposition interaction, the most objective method is to calculate the critical loading for a specific soil. It is the calculation of a sort of threshold, crossing of which leads to soil damage. The principal is to find out a neutralization capacity of environment (soil + vegetation) that enables to eliminate superfluous hydrogen cations infusing into the soil system from the outside. The tolerance of specific soil classification types is very changeable and it is impossible to pinpoint the critical value out of the very broad intervals of analytical values (such as absorption capacity dimension and degree of absorption complex saturation, pH, COx), agglomerated into land evaluation units.

The principal degradation process caused by soil acidification impact is regarded to be leaching of basic K, Ca and Mg cations which causes nutrients deficit. Furthermore, the mobilization and concentration of toxic metals and aluminium – as common elements of the soil mantle – in the soil solution that causes damage not only to plants but also the fauna of rivers/waterways and lakes.

Pollutant limits for vegetation protection

Pollutant limits have been so far assessed with respect to the protection of population health. In 1980s and 1990s first pollutants limits proposals and vegetation protection proposals appeared as a result of developed knowledge of air pollution impact on vegetation. Several organizations proposed pollutants limits for vegetation and agricultural crops protection against air pollution negative effects and these limits were assessed by a law in many countries (see table 1, 2, 3).

Table 1 Pollutant limits for vegetation protection against ozone effects (according to Lauril, Latill 1994 and Slooff 1987)

Interval of measurement	*Immission limit (μg/m³)*	*Notes*	*Sources*
1 h	150	guideline	NMR 1990, UN-ECE 1988
1 h	200	guideline	WHO 1987, CEC 1992
8 h	60	guideline	UN-ECE 1988
24 h	65	guideline	WHO 1987, CEC 1992
growing season	50	10–17 h	NMR 1990, UN-ECE 1992
growing season	60		WHO 1987
1 h	150		Slooff 1987, Nizozemsko
8 h	65	9–17 h	Slooff 1987, Nizozemsko
growing season	50	10–17 h, May–September	Slooff 1987, Nizozemsko

Table 2 Pollutant limits for vegetation protection valid in Austria (according to UBA 1995)

Type of vegetation	*Pollutant*	*Season*	*30 min (μg/m³)*	*24 h (μg/m³)*	*97,5 % month (μg/m³)*
coniferous	SO_2	4–10	140	50	70
		11–3	300	100	50
	HF	4–10	0,9	5	
		11–3	4	3	
	HCl	4–10	400	100	
		11–3	600	150	
	NH_3		300	100	
deciduous	SO_2		300	400	
	HF		6	3	
	HCl		600	200	
	NH_3		300	100	

Table 3 Pollutant limits relating to vegetation and agricultural crops valid in EC

Pollutant	*Immission limits*	*Notes*
SO_2	20 μg/m³	except urban area, valid since 19. 7. 2001
NOx	30 μg/m³	since 19. 7. 2001
PM_{10}	40 μg/m³	maximum exceed of value more than 35x per year
O_3	3000 ppbh	3 months of growing season, AOT_{40}, 1ppb = 2 μg/m³

In order to evaluate the interaction of air pollutants with soil and plants covering the whole area, we have chosen a single information source both for soils and for pollutants concentrations. This information has been processed in a map form in the GIS system as thematic layers. For the evaluation of soil part the evaluated units were chosen, for pollutant concentrations or depositions the data were drawn from ISKO, collected by ČHMÚ and published in ČHMÚ yearbook.

The method is based on a synthetic evaluation of average concentrations and depositions of four principal air pollutants in 1990–2000. These are hydrogen ions (H^+ – annual dry and wet deposition measured in mg/m^2) for an indirect influence as an acidifying component and sulphur dioxide (SO_2 – field of annual arithmetical concentrations averages measured in µg/m^3), dust aerosol (SPM – field of annual arithmetical concentrations averages, in µg/m^3), ozone (O_3 tropospheric – field of exposition index values for ozone AOT with agricultural crops, in ppbh) and nitrogen dioxide (NO_2 – field of annual wet deposition, in g/m^2) as the components with a direct influence on vegetation. Table 4 shows pollutant limits for each of substances, which define the range/ cline of air pollution in three categories: mild pollution – middle pollution – strong pollution. To assess these, literature search data were used.

Table 4 Limit concentrations of selected air pollutants

Pollutant	Concentration			Method of evaluation
	Low	Middle	Strong	
H^+	less than 100	100–250	more than 250	annual deposition (mg.m^{-2}.year^{-1})
SO_2	less than 20	20–40	more than 40	mean concentration (µg.m^{-2}.year^{-1})
O_3	less than 7,900	7,900–10,500	more than 10,500	AOT_{40} (ppbh)
SPM	less than 30	30–50	more than 50	mean of concentration (µg.m^{-3})
NOx	less than 0.5	0.5–1.5	more than 1.5	annual deposition (g.m^{-2}.year^{-1})

The indirect influence category differentiates areas by a total H^+ deposition. An initiated acidification, and consequently the increased expenses on agromelioration measures – liming, correlates with a natural soil capability to be resistant to this external impact. Buffering power BPEJ is the resistance of soil (fine earth) and ecological factor (climate, profile thickness and skeleton contents) in point's formulation (Fig. 1). The following points are regarded as partial buffering factors:

- Absorption capacity force – T (mekv/100g),
- Absorption complex saturation – V (%),
- Climatic circumstances of the site – K (by land valuation codes of climatic regions 0–9),
- Depth of soil profile (shallow – middle – deep),
- Skeleton contents including rock type – less than 25% of contents, more than 25%,
- Pollution categories divided into three degrees are in Table 4.

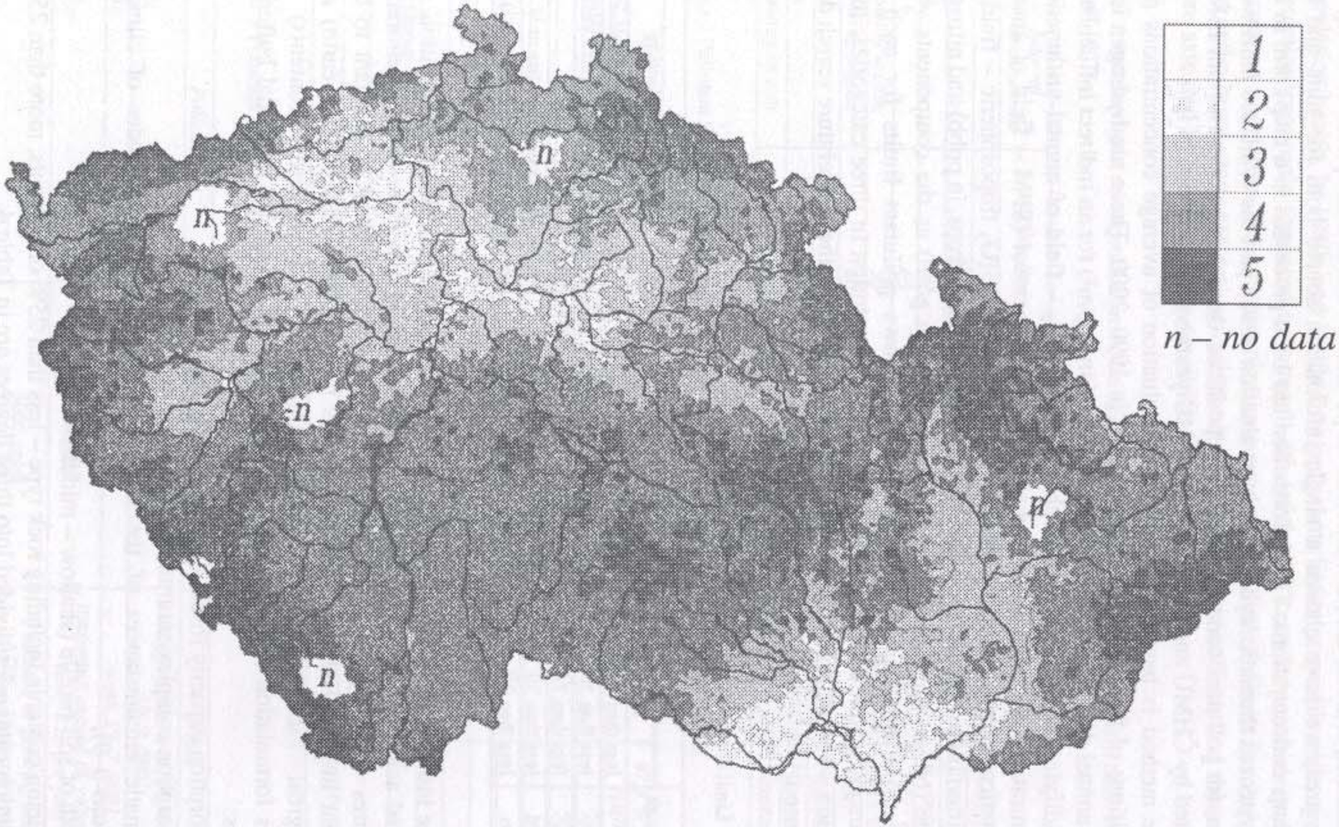

Fig. 1 Mean buffering capacity of soil by cadastral areas
Key: 1 – very low, 2 – low, 3 – middle, 4 – high, 5 – very high

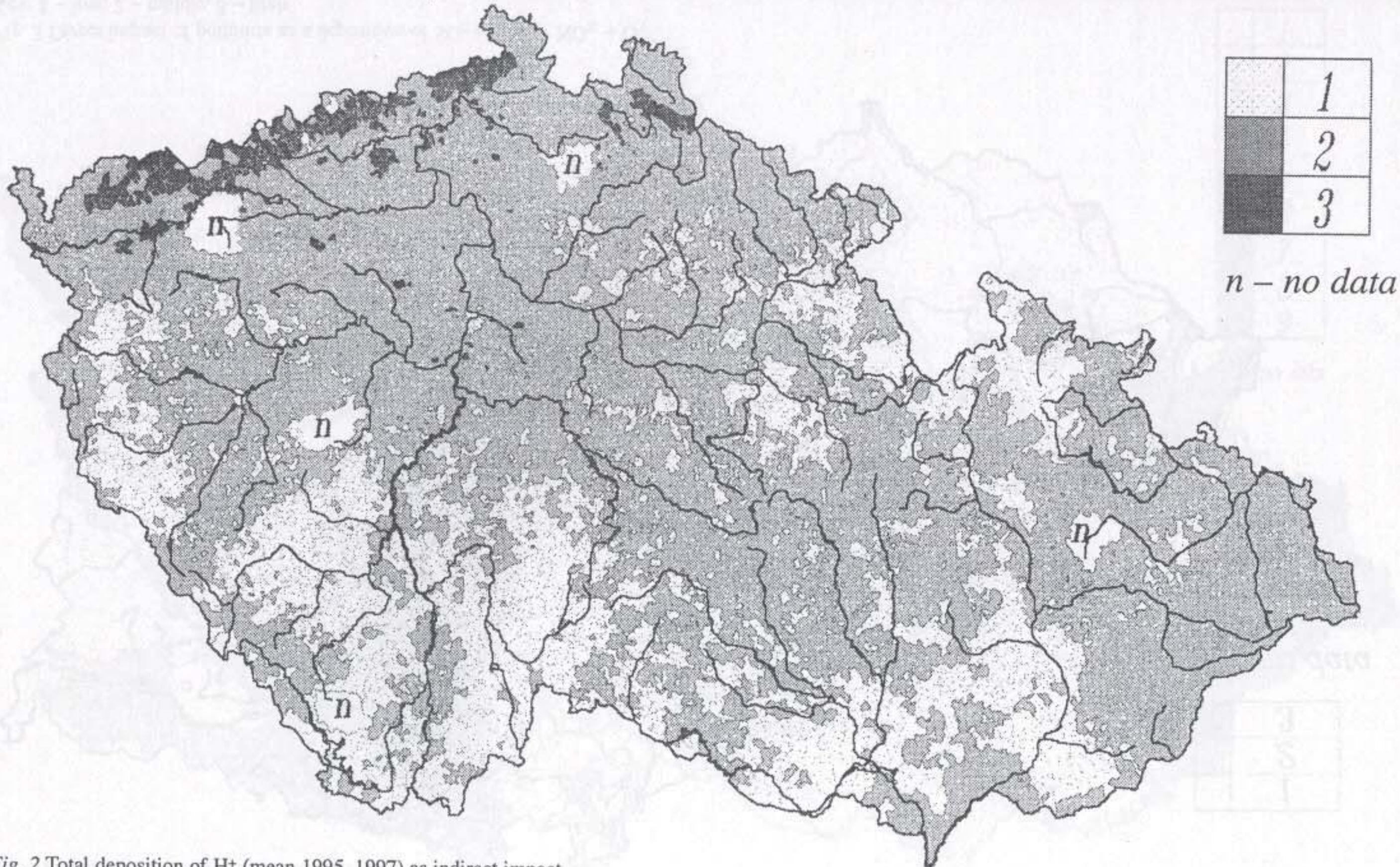

Fig. 2 Total deposition of H^+ (mean 1995–1997) as indirect impact
Key: 1 – low, 2 – middle, 3 – high

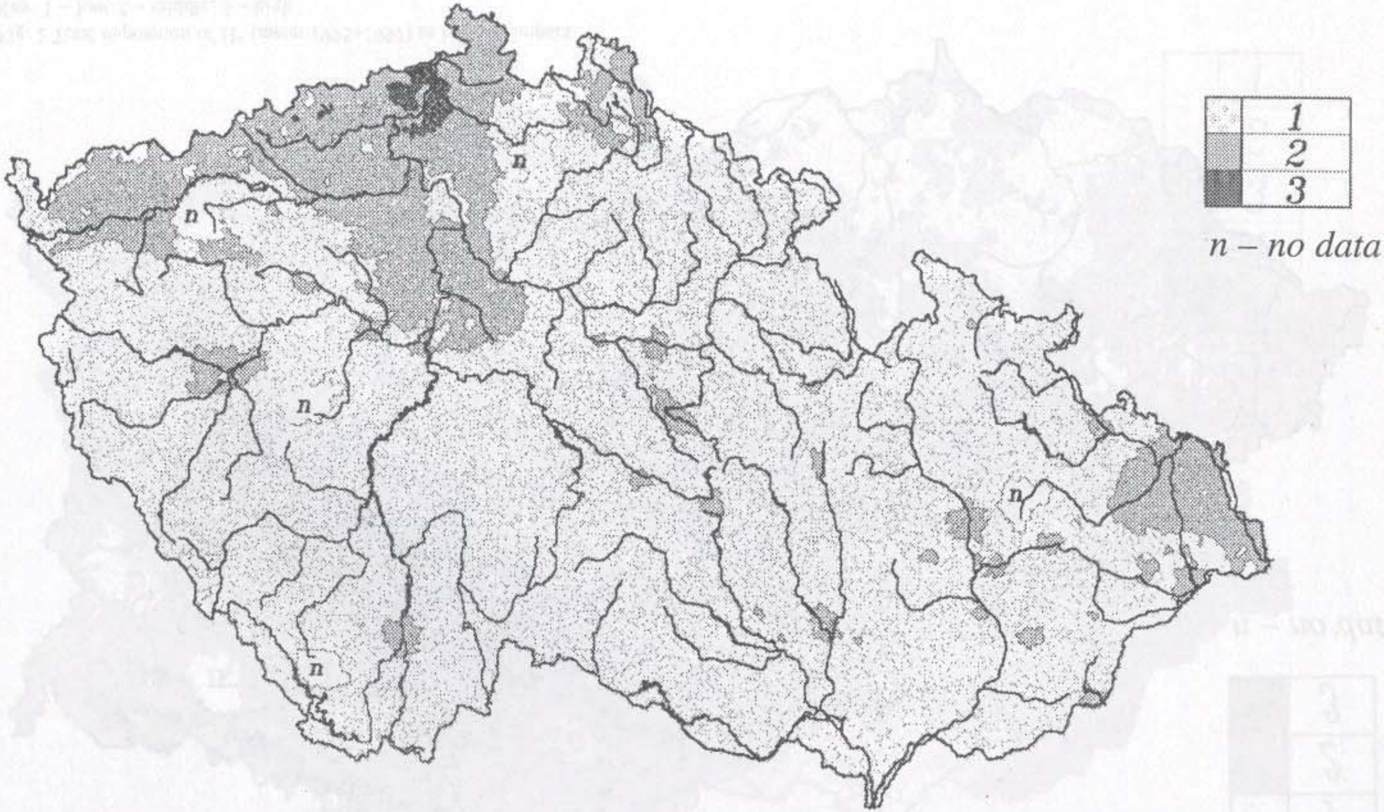

Fig. 3 Direct impact of pollution as a deposition of SO_2 + SPM + NO_X + O_3
Key: 1 – low, 2 – middle, 3 – high

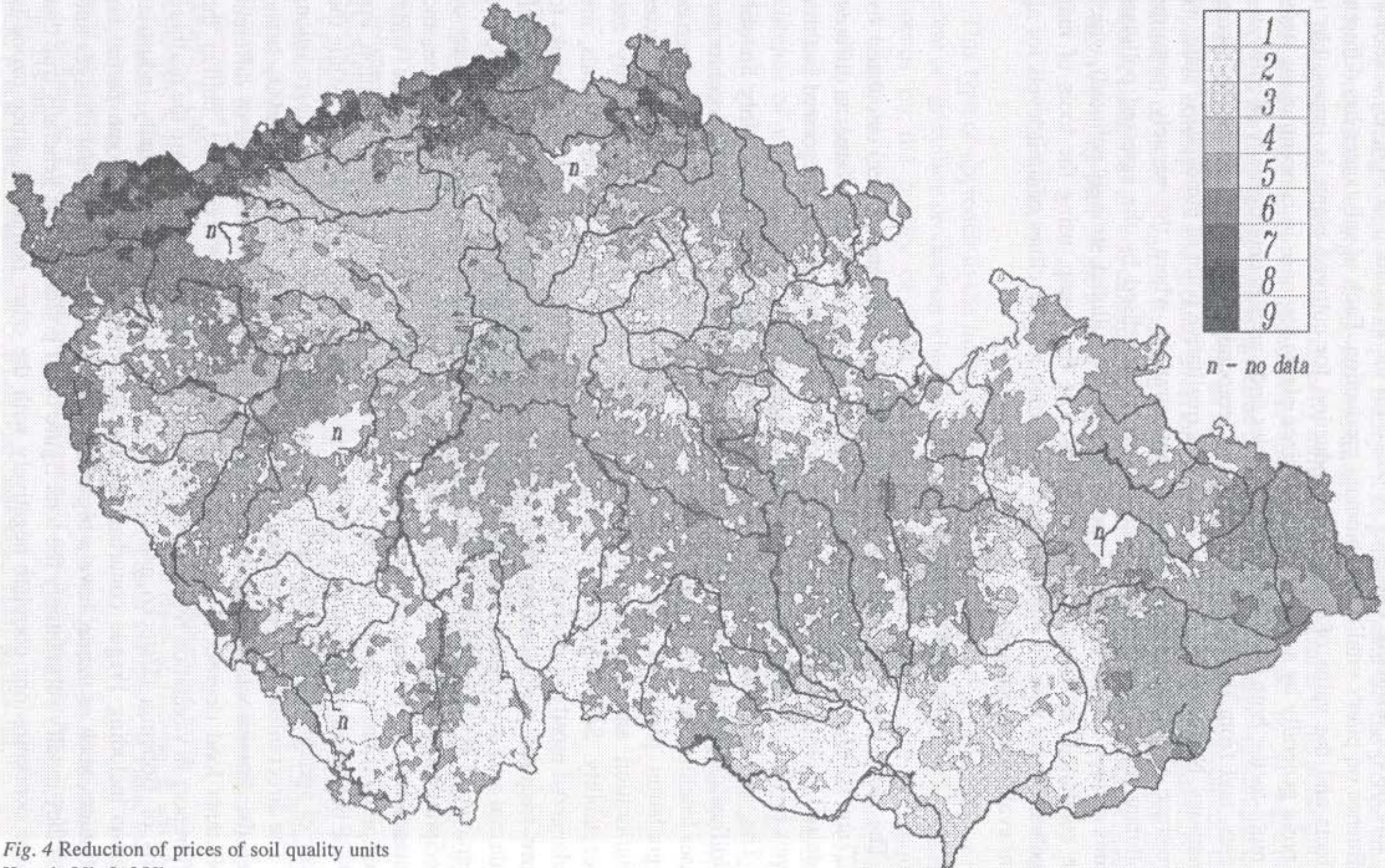

Fig. 4 Reduction of prices of soil quality units
Key: 1–0%, 9–25%

The direct influence category is based on the evaluation of SO_2, O_3 and SPM influence on plants vitality and biomass production. Each of substances has different effects and the value of decreased production for cultured plants is impossible to express generally by a solitary number since plants response to concentrations states is multi-factor, both from the point of species and varieties heterogeneity of cultivated plants, and from the point of spatial and temporal unsteadiness of meteorological situations. Nevertheless, in order to use this qualitative point of atmospheric state, we construct a synthetic index map of concentrations where the vaguely measured pollutant levels of different substances are standardised by the assessed pollutant limits in three categories (without pollution, middle polluted, strongly polluted), which are combined, as dimensionless numbers. The final map, using the tools of map algebra, creates new, in legislation not embodied ranges/ clines of limit levels for all four evaluated substances.

Results and discussion

The result is a synthetic map combining soil buffering power, calculated for different BPEJ units and expressed in the map by average buffering values in different cadastral areas and pollutant load where selected substances are categorized in three levels by their negative influence on soil and plants.

The indirect influence on agricultural production consists mainly in soil acidification according to total hydrogen ions deposition that leads to pH decrease and bases leaching from absorption complex. This process is linked to a long sequence of degradation processes, such as microbial activity decrease, physical character deterioration and heterogeneous substances (e. g. heavy metals) mobility and acceptability. Soils which are naturally acid from bedrocks low in minerals, are endangered mostly in mountain areas where H^+ wet deposition is the largest thanks to more frequent precipitations. The buffering class of soils is calculated for each cadastral area as weighted average of individual BPEJ buffering in each cadastral. The character of H^+ deposition spatial allocation (Figure 2) is close to the character of precipitation total, and it correlates therefore also with a higher soil percolation, and consequently with the share of luvisol, pseudogley soils and podsolic soils. Precipitation unsteadiness can change substantially a total plot of H^+ deposition, but all the border mountain chains possessing a very low natural soil buffering (while the share of agricultural soils is small) continue to be mostly endangered by degradation.

The direct influence is expressed by the synthesis of SO_2, SPM, NOx and O_3. In the map the dimensionless units are developed according to the sum total of different pollutants load degrees (Figure 3). Their interaction is not evaluated, neither the differences in vegetation reactions are. The most strongly struck areas are the northern parts of Bohemia (Ústecko and Děčínsko), and the other traditionally industrial regions including Prague conurbation have also many problems. Some partial air pollutants, such as ozone, have a big dynamics of seasonal and annual changes and thus they modify substantially the total figure of air pollution. It is generally true that ozone concentrations correlate negatively with the other pollutants, since ozone is a strong oxidizing agent. For example Budějovická pánev – basin has the second stage of load only thanks to high ozone concentrations.

The synthesis of directly and indirectly influencing air pollutants in the atmosphere is depicted, after being combined with soil quality (represented by its buffering power), in the map where each range/cline corresponds to a percentage agricultural tax allowance (see Fig. 4). It is therefore an interpretational output, which documents the impact of atmosphere and ground cover on plant growing. The biggest possibility of reduction, up to 25%, can be found in the mountains of Krušné hory, while the most frequent categories are not-damaged and middle-damaged with a 15% allowance, each of them covering 30% of the area of Czech Republic.

Conclusion

This type of approach to the interaction of polluted atmosphere and living part of nature or agriculture production which is closely connected to the living part of nature, depends on the quality of input data of thematic soil layers and pollutants concentrations. In every case, the objectiveness of synthetic output and our chances to use them at local stage (e. g. cadastres and/or parcels) is determined by precise pollutant monitoring, perfect interpolation of measured data in the whole area and the existence of vector soil layer at subtypes level. Big dynamics of the changes in pollutant contents measured in the atmosphere makes the results of synthesis relatively fast outdated, therefore it is necessary to come up with an actualization every five years.

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ZNEČIŠTĚNÍ OVZDUŠÍ A JEHO VLIV NA ZEMĚDĚLSKOU PRODUKCI

R é s u m é

Článek se zabývá vlivem znečištěného ovzduší na zemědělskou produkci metodikou výpočtu úlev pro zemědělce hospodařící v imisně zatížených oblastech. Znečištěné ovzduší ovlivňuje zemědělskou výrobu přímo a nepřímo. Jako složky přímo poškozující vegetaci byly použity oxid siřičitý (SO_2 – pole ročních aritmetických průměrů koncentrací v $\mu g \cdot m^{-3}$), prašný aerosol (SPM – pole ročních aritmetických průměrů koncentrací v $\mu g \cdot m^{-3}$), ozón (O_3 troposférický – pole hodnot expozičního indexu pro ozón AOT_{40} pro zemědělské plodiny v ppbh) a oxid dusíku (NO_3 – pole roční mokré depozice v $g \cdot m^{-2}$). Pro nepřímé působení jsou uvažovány vodíkové ionty (H^+ – roční suchá a mokrá depozice v $mg \cdot m^{-2}$) jako okyselující složka. Obecně naměřené imisní úrovně jednotlivých látek jsou normovány stanovenými imisními limity do tří kategorií (neznečištěné, středně znečištěné, silně znečištěné), a ty jsou jakožto bezrozměrná čísla slučována. Výsledná mapa, využívající nástrojů mapové algebry, vytváří nové, legislativně nezakotvené areály limitních úrovní všech čtyř hodnocených látek. Syntéza přímo a nepřímo působících znečišťujících látek v atmosféře je po kombinaci s kvalitou půdy (zprostředkovanou její pufrační silou) vyjádřena mapou, kde jednotlivé areály odpovídají procentické úlevě na dani ze zemědělské půdy (obr. 4). Jde tedy o interpretační výstup, který dokumentuje působení atmosféry a půdního krytu na rostlinnou výrobu.