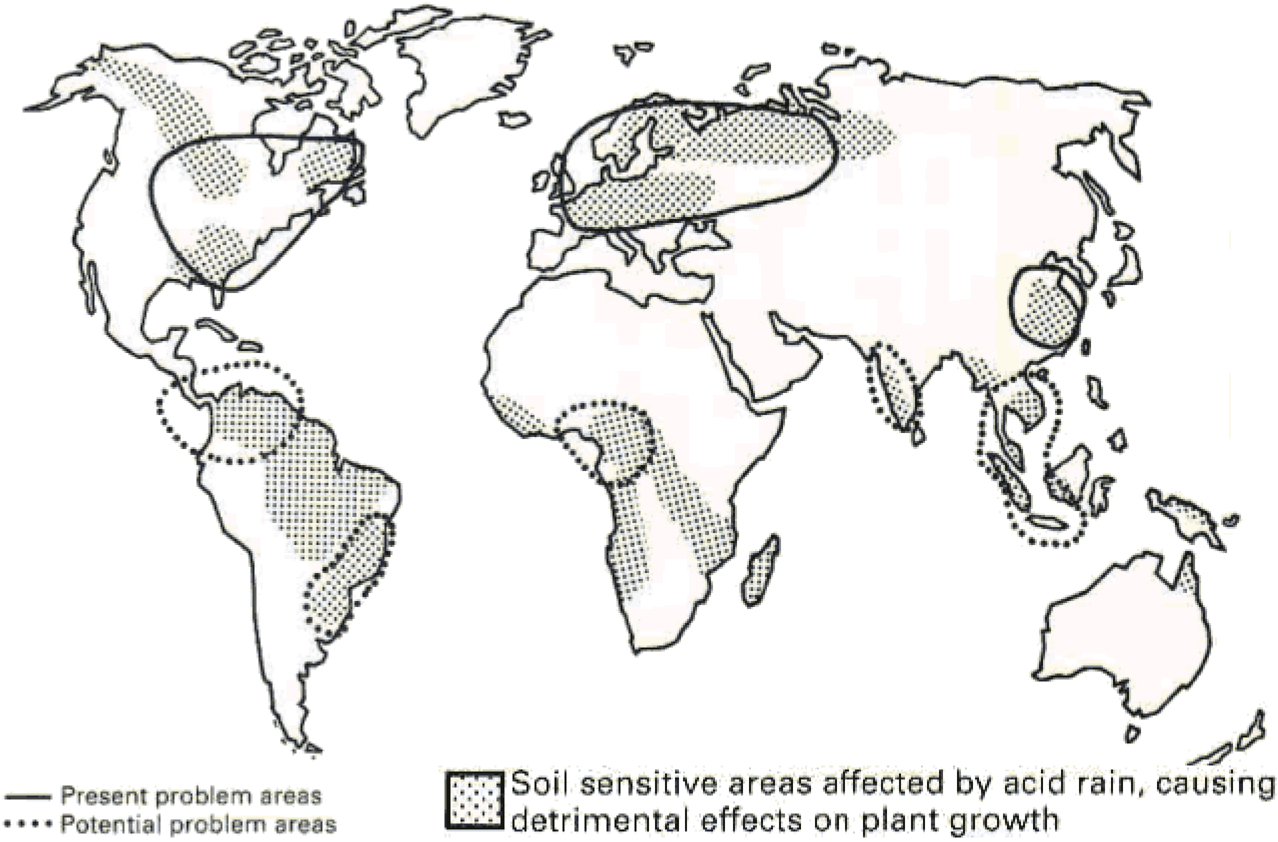
The consequences of acid rain on our environment

By Barbaroux Florent and Michel Yann

Main question

1. Observation :

Acid deposition can take two forms : acid precipitations, which forms the "acid wet deposition", or acid gases and salts, which form the "acid dry deposition".
Precipitations are naturally acid, because of the atmospheric carbon dioxide (CO_2), which, dissolved in the water, makes some carbonic acid (H_2CO_3). The natural acidity of the precipitations is about pH=5,6. Below this value, the precipitations are known as "acid precipitations".
Acid deposition is distributed as this world chart shows us :

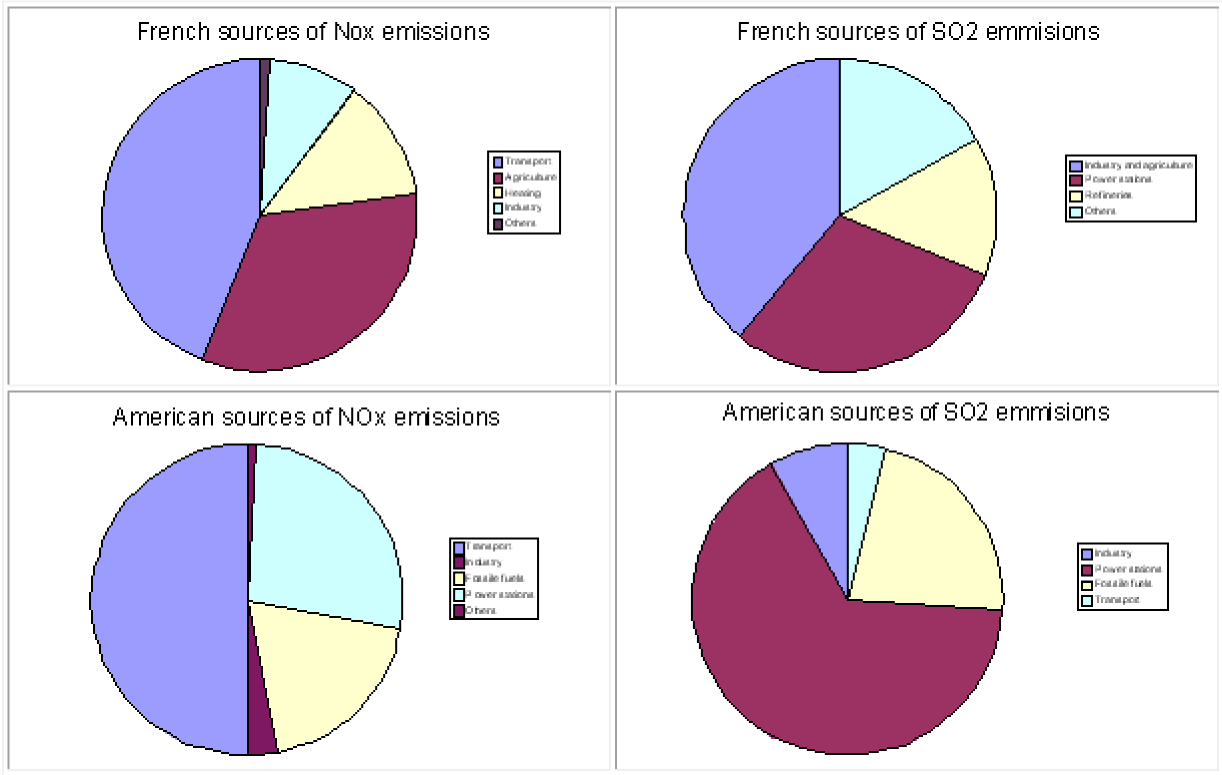


But, in many industrial countries, we can observe that the precipitations are more acid than the natural value, for instance :
- In France, the common acidity of rains is pH=4.5 and the acidity of fogs and drizzle can reach pH=3.
- The acidity can be higher : in the USA, the acidity reached pH=2,3 in 1978 and pH=1,5 in 1979.

The great acidity of the precipitations is due to the presence of pollutants in the atmosphere, which react with the water molecules , thanks to a catalyst, the hydroxyl (OH), to form acids : sulphuric acids (H_2SO_4) and nitric acids (HNO_3).

The mechanism of the formation of the acid precipitations is the following :
- Cis of the O_3 molecules in the stratosphere : $O_3=O_2+O$
- Formation of the catalyst, OH : $O+H_2O=2OH$
- Formation of the sulphuric acid H_2SO_4 : first $O_2+SO_2+OH=SO_3+HO_2$ ... then $H_2O+SO_3=H_2SO_4$ ... or $2HO_2=H_2O_2+O_2$ ... then $H_2O_2+SO_2=H_2SO_4$
- Formation of the nitric acid HNO_3 : either $NO_2+OH=HNO_3$ ... or $NO+OH_2=NO_2+OH$ ... then $NO_2+OH=HNO_3$

These pollutants, which are sulphur dioxide (SO_2) and nitrogen oxides (NO_x), can come from natural sources (like volcano), but they mainly come from the human activity :

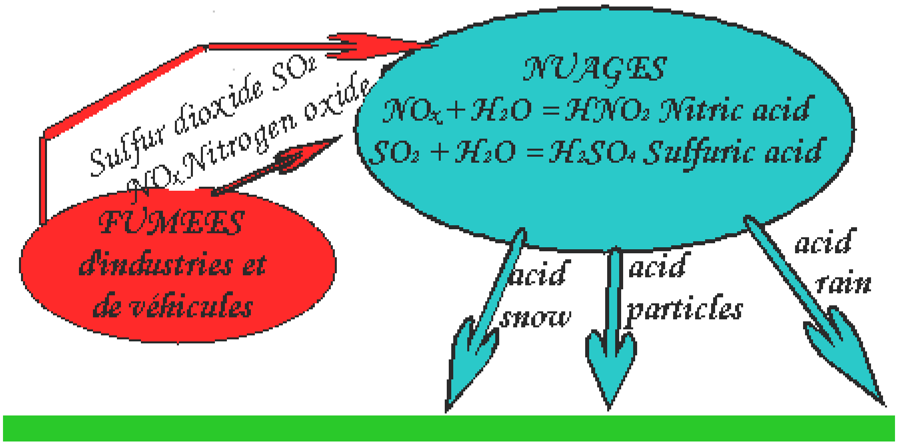


But a part of the pollutants do not react with the water and can be transformed into gases or salts which fall on the ground by the influence of the gravity. This gases and salts formed the acid dry deposition.

By falling on the ground, acid precipitations and acid gases and salt, form the acid deposition :

Acid deposition in France (1990-1999) (tonnes)				
	sulphur dioxide (SO_2)		nitrogen oxides (NO_x)	
	1990	1999	1990	1999
Deposition	**580 000**	**320 000**	**720 000**	**850 000**
Come from France	**180 000**	**130 000**	**440 000**	**600 000**

Here is the cycle of acid precipitation :



We are about to study the acid wet depositions called "acid rains" or "acid precipitations".

2. Question :

What are the consequences of the acid deposition on our environment, more precisely on the flora ?

3. Hypothesis :

Acid precipitations may attack the plants slowly, causing the death of these plants.

Experimental check :

1. Experimental protocol

We will study the action of acid precipitation on plants by imitating the common acidity (PH) of rain in France, and by imitating the higher acidity rate that American rain had reached. Then we will put some lichens in presence of this reconstituted acid rain and observe their reaction to the acidity after a period of approximately a month. We will observe the differences in the oxygen's concentration by studying the breathing and the photosynthesis of the lichens in non acid solution, then in acid solution and finally in very acid solution thanks to a computer-assisted experiment material.

We will need :

- Some lichens we took from the trees around the school. These lichens are from a polluted area, so they resist more to the acidity than lichens from a clean area.
- A system of computer-assisted experiment measuring the variations of oxygen concentrations in an aqueous medium. It is composed of a vat containing the lichens as well as the solution, an agitator, a probe measuring the oxygen concentrations, a lamp providing the light necessary to photosynthesis.
- A computer with the software which records the results of the computer-assisted experiment material.
- Glassware : beakers (250 mL, 2 L).
- An apparatus which measure the pH of a solution.
- Sulphuric acid.
- Tap water.
- Material of taking.

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<td>We crushed the lichens in order to increase the exchange area between cells and the solution. Then we put the lichens pieces in three vats like this one :
- To confirm the results of the experiment, we put lichens in non acid tap water.
- lichens in imitate acid rain (tap water + drop of acid = 1,5pH)
- lichens in imitate acid rain (tap water + drop of acid = 4,5pH)

When we obtain the desired acidity, we add 7 mL of the solution in the vat, so that when we put the probe inside, there is no remaining air in the medium. We activate the agitator to facilitate the exchange between the cells and the solution.</td>
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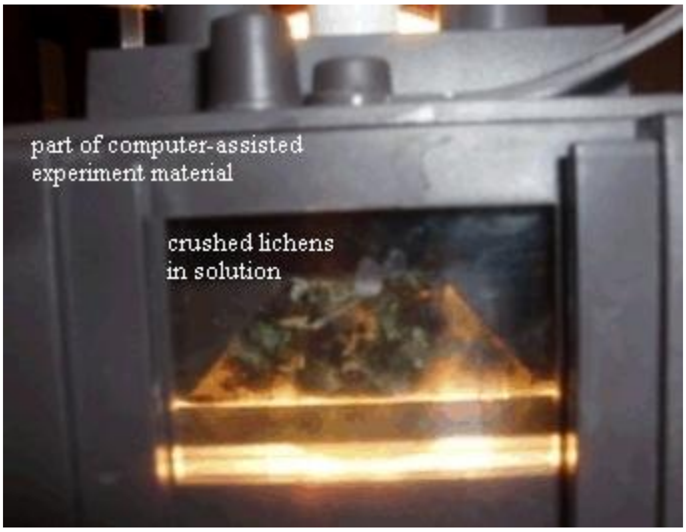
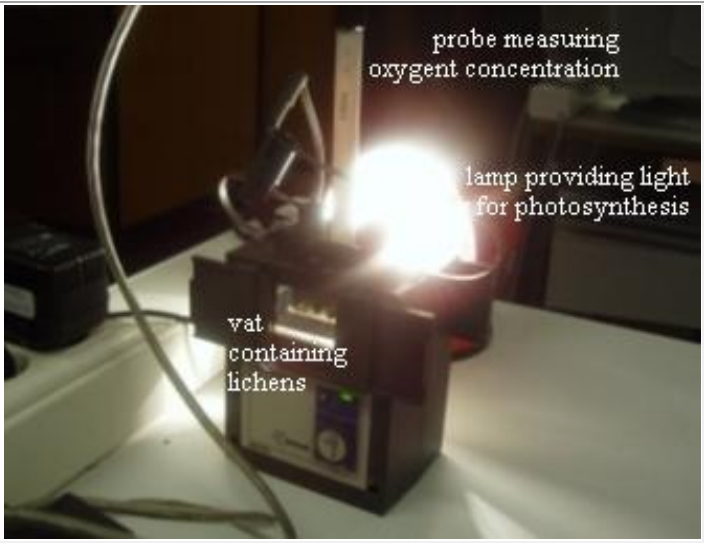


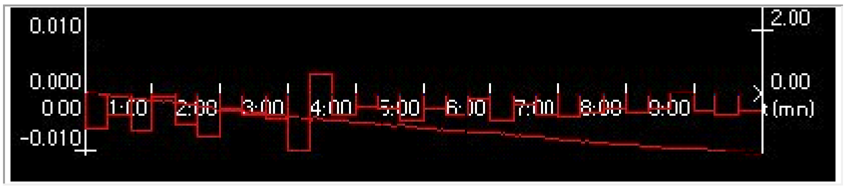
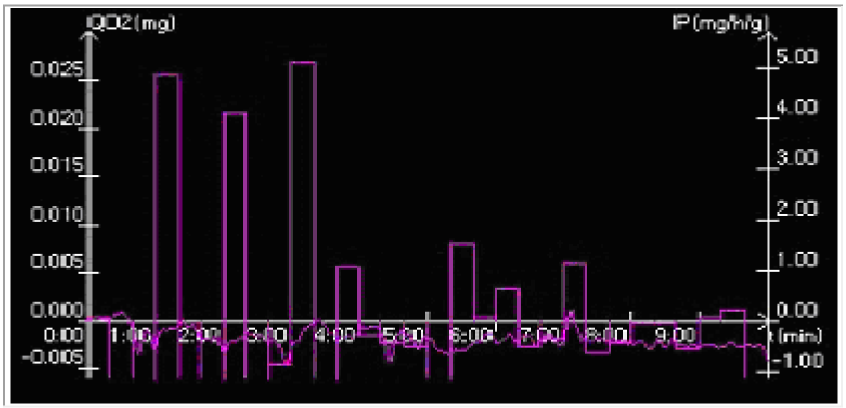


Then we launched the software measuring the photosynthesis of the lichens contained in the solution which created the graph indicating the concentration of oxygen in the solutions for 10 minutes.

After the experiment, we closed the vats containing the solutions so that they would not evaporate, and therefore the solutions will be able to work on the lichens. We waited for a month.

2. Results

In the first part of the experiment, we chose a software which measures the oxygen's concentration (QO_2) and also the photosynthesis of plants (IP) according to time.

Solution 1 : oxygen's concentration and photosynthesis in a pure tap water solution (PH = 7.5) according to time.	
Solution 2 : oxygen's concentration and photosynthesis in an acid solution (PH = 4.5) according to time.	
Solution 3 : oxygen's concentration and photosynthesis in another acid solution (PH = 1.5) according to time.	

Were we can't observe the bottom of the histogram because we forgot to change the scale and because the columns were too big, but we can guess their position by the curve of the oxygen's concentration.
We can observe that in the first and in the second solutions, the oxygen's concentration decreased throughout the whole experiment, but in the third solution we could observe that the concentration had increased by moments because of the photosynthesis. This was because the lamp was too close.

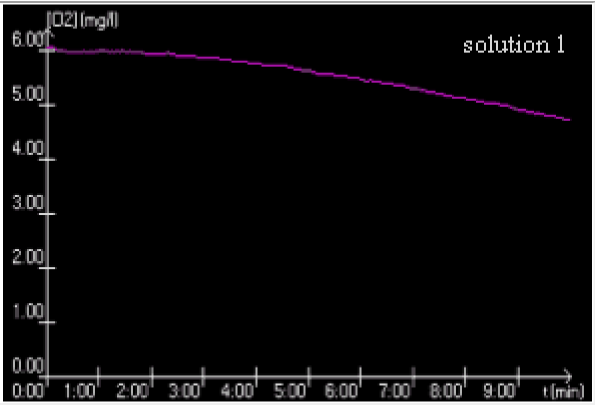
In the second part of the experiment, after one month, we could observe that in the acid solutions the lichens had adopted a grey colour. It showed us that there was a sulphur deposition, which had come from sulphuric acid, onto the lichens. So we guessed that the solution had attacked the lichens.

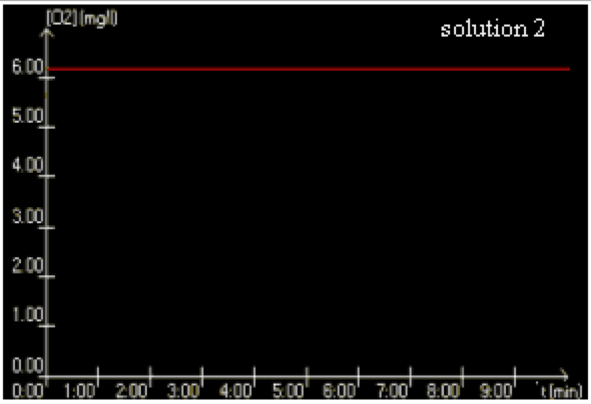
In this part of the experiment we chose to measure only the variation of the oxygen's concentration according to time instead of the the photosynthesis, because we observed in the first part of the experiment that the lichens we used only breathed (except in the third solution), so the concentration only decreased and we could not observe the results correctly.

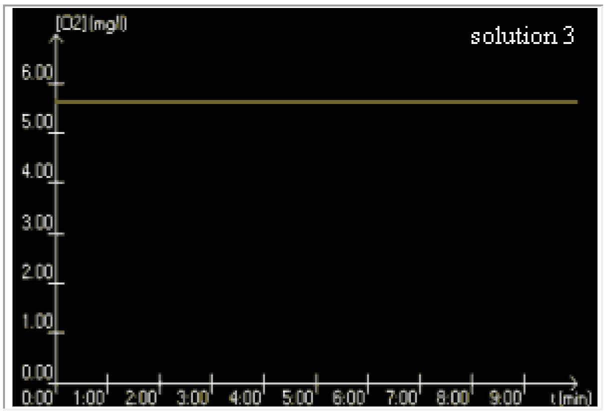
Solution 1 : oxygen's concentration in a pure tap water solution (pH = 7,5) according to time.

Solution 2 : oxygen's concentration in an acid solution (pH = 4,5) according to time.

Solution 3 : oxygen's concentration in another acid solution (pH = 1,5) according to time.







We can observe that the oxygen's concentration only decreased in the first solution whereas it is still the same throughout the whole experiment in the acid solutions

3. Interpretation

In the first part of the experiment, we can explain the decrease of the oxygen's concentration in the solutions by the lichen's breath. In fact, there is no reason for chimical oxydation in the water that don't contain many oxygen molecules, so the reason for this decrease is a biochimical one : the only one possible is the breath of the lichens. Let us recall that the reaction which allows for breathing is the following : $C_6H_{12}O_6+6O_2=6CO_2+6H_2O$+energy, and happens in the presence of enzymes catalysing the reaction of $C_6H_{12}O_6$ molecules. Moreover this reaction can happen only in live beings, so we can say that the lichens are still alive in all of the solutions in the first part of the experiment.
We thought that if we did not observe any photosynthesis (except for the third solution), this reaction being the reverse of the breath ($6CO_2+6H_2O$+energy=$C_6H_{12}O_6+6O_2$), although there was not any light and heat, it is because the lichens were in period of slowed down life, the normal reaction of plants in the winter which allowed them to protect themselves from external conditions, so the enzymes catalysing this reaction did not work, and so the reaction did not happen.

In the second part of the experiment, the lichens are symbiotic plants ; there are thus two partners : on the one hand an algae or a cyanobactery, called phycosymbiote, on the other hand a fungus, called mycosymbiote, which forms a "carapace". If the carapace of lichens is destroyed, the cells of the phycosymbiote are vulnerable to external attacks, and, as these cells are the "heart" of lichens, these ones can die.
For the first solution (tape water) we observed that the oxygen's concentration had decreased during all the experiment, so the lichens could still breath (we already explained that it is the only possible reaction), so they were still alive. We could deduce that the acidity of tap water (7.5, acidity close to the neutral value) was not strong enough to attack the lichens' carapace or not enough to reach the cells of the mycosymbiote, at the origin of the breathing and the photosynthesis of the lichens.

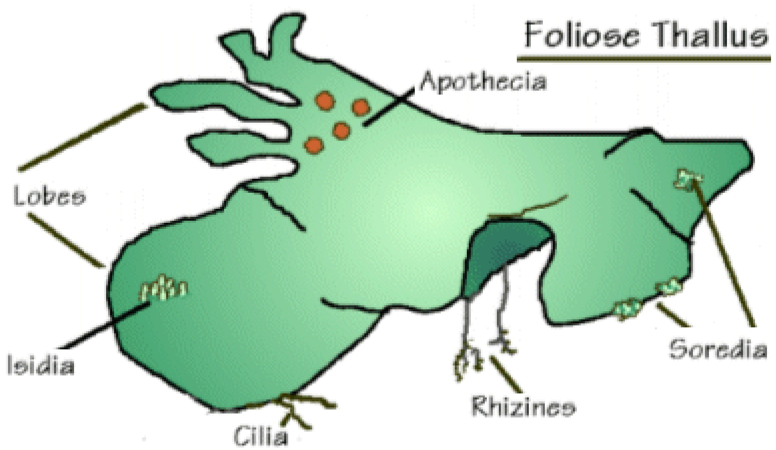
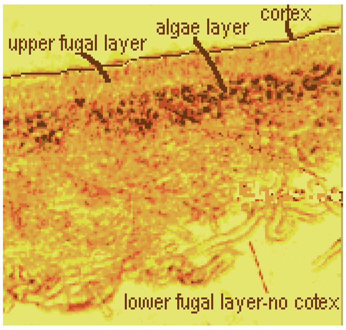


diagram of a alive lichen of thallus type



photograph of the cut of this alive lichen

In the two acid solutions (pH=4,5 or pH=1,5) we observed that the oxygen's concentration had not increased or decreased, so the lichens did not breath, so they were died. We could deduce that the acidity of the acid solutions, contrary to the first solution, was strong enough to attack the phycosymbiote and to destroy it. Then, acidity finally reached and destoyed the cells of the mycosymbiote that allowed the lichens to breath and to produce photosynthesis. So, the acidity killed the lichens.

Conclusion

Verification of the hypothesis

We observed that the lichens in presence of acid had died after a while (neither breath nor photosynthesis), so we can say that acid rain attacked the plants slowly, destroying their cells and so killing them.
So our hypothesis is correct.

Broadening

More generally, in the areas concerned by acid deposition, plants are more or less the target of the acid deposition, which cause, with time, an attack at the cellular level, killing gradually the plants.
Now we know that acid deposition has an impact on plants, but it also has an impact on animals and also on humans.

Acid deposition can increase the impact that climatic conditions have on buildings, and particularly on old buildings built with limestone, marble or sandstone. In fact, acid rain dissolve their calcium carbonate, creating layers of calcium sulphate or gypsum which are removed more easily by precipitation. Thus, in the whole world, monuments and old buildings need continuous renovation because they were built with these materials, that is not the case of new buildings.

In aquatic environments, acidity in water can cause the death of some animals (first micro-organisms like insects and planktons from a PH of 6), which gradually spoils the food chain of this ecosystem. It can also cause the death of all animals when the PH is below 5. We can also observe this phenomenon for land animals, but it is less effected if these animals do not take part in the water ecosystem.

Finally, the indirect effects of the acid deposition on humans (along with also the effect of fertilizers) are : acid rain falls onto the ground which provides food to animals, and which produces fruit and vegetables. However, meat and products from the ground constitute the food for humans. To eat such food can induce various bad effects on human health, amongst which magnesium deficiency.

What can we do to limit the phenomenon of acid deposition ?
As the the pollutants causing acid deposition mainly come from useless trips in cars and excessive consumption

of electricity, the first advice we can give you is not to only use your car for small journeys and to shut down all your apparatuses using electricity when you have finished using them.

Then, there are a lot of things we can do :
- Only run the dishwasher and the washing machine with a full load.
- Turn off all the lights when you leave a room.
- Turn off the electricity and the hot water water tank when you will not be at home for a long period of time.
- Turn down the heat when you are not at home.
- Do not use your air conditioner as much.
- Install fluorescent light bulbs instead of incandescent light bulbs.
- Try to reduce, reuse, and recycle as often as you can.
- Try not to burn a fire as often as you usually do.
- When you are going to work : you could walk, ride, bike or take a bus.
- Car-pool to a place with someone else.
- For alternate fuels, try ethanol, propane or natural gas.
- Take a train or a bus for long trips.
- Limit the amount of long trips you take in your car.
- Make sure that your vehicle's air conditioning system isn't leaking.
- Try not to overflow the gas tank.
- Try to respect the speed limits...

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What are lichens?

Symbiosis : Lichens are formed from a combination of a fungal partner, this is the fungus which is termed by scientists mycobiont, and an algal partner, this could be an algae or cyanobacteria which is termed by scientists phycobiont. This symbiosis can't be formed by each algae and fungus. When the symbiosis can be formed, they make a unique type of thallus. Before the lichen is formed the algae and fungus may lives in nature without its partner. When the thallus is formed they can't survive without each other. The morphology from the individual fungus is quite different from the morphology from the lichen.
Fungus / Mycobiont : The fungal partners are mostly (over 95%) Ascomycota, and a few fungus (approximately 20 sorts) are Basidiomycota. Almost half of the recorded fungus in the world are Ascomycota, and nearly half of these are found only in lichens. One sort of fungus is only used by one sort of lichen. So the names of lichens are grounded on the fungus. Only 20% of the recorded fungus in the world are used to make lichens. The mycobiont has two roles in the lichen symbiosis: to protect the photobiont to intense sunlight and to absorb mineral nutrients.
Algae / Photobiont : There are only about 100 algal partners, so one sort of algae is used to make different species lichens. Not all the algal partners can exist in all species habitats, with these a lichen has a small habitat. But normally a lichen has a great distribution. In alpine regions single-celled green algae of the genus Trebouxia and Cladonia are the most common. Trebouxia is specialised in lichen symbionts. In Mediterranean and tropical regions especially grow green algal genus Trentepohlia. Also Cyanobacteria can be used as algal partner. But only 10% of lichens have cyanobacteria as partner. Sometimes a lichen exist from a green algae and a cyanobacterium, these lichens are termed cephalodia. Only 3-4% of the recorded lichens have this structure. The photobiont has two roles: to make organic nutrients from carbon dioxide and to produce ammonium from N_2 gas.
Reproduction : There are two different forms to reproduct. Lichens can reproduct with non-sexual

reproductive packages like soredia and isidia.
1. Soredia is a form to reproduce itself, when a cluster of algal cells wrapped in the fungus this forms a new lichen after the disperse.
2. Isidia is like Soredia but is enclosed with a little skin, like a tissue. To form a new lichen, fungus can produce spores, the fungal spores need new photosynthetic partners. Some steal them from other lichens, others have partners upon themselves.

Information : The alga will begin to use sunlight to make sugars or food which will feed both the fungus and the alga. The fungus will create a thallus or body that will house both organisms. Thus, through the lichen partnership, the photobionts are protected and able to grow in conditions in which they could not grow alone; they also benefit from the highly efficient uptake of mineral nutrients by the lichen fungi. The fungi, in turn, obtain sugars and in some cases organic nitrogen from the photosynthetic partner, enabling them to grow in environments deficient in organic nutrients.

Life History & Ecology : Lichens will grow almost anywhere that a stable and reasonbly well-lit surface occurs. This may include soil, rock, or even the sides of trees. A lichen may absorb certain mineral nutrients from any of these substrates on which it grows, but is generally self-reliant in feeding itself through photosynthesis in the algal cells. Thus, lichens growing on trees are not parasites on the trees and do not feed on them, any more than you feed on the chair you sit in. Lichens growing in trees are simply using the tree as a home. Lichens growing on rocks, though, may release chemicals which speed the degradation of the rock into soil, and thus promote production of new soils. Most lichens are temperate or arctic, though there are many tropical and desert species. Lichens seem to do better in drier environments, where they are not often left in standing water. What the lichen considers dry, however, may not be what we would consider to be dry. In bayous and in cool rainforests, large lichens known as "old man's beard" may often be seen hanging from the branches of trees. Though there is considerable water in these habitats, the air is not saturated, and drying breezes may serve to dessicate arboreal organisms.

Growth and Development : Like all living things lichens need nutrients and energy to grow. Nutrients they obtain from the air (including dust), water and some from the substrate they are growing on. Energy they obtain through photosynthesis, which is the role of the algal partner. They can also be incidentally fertilised by bird and insect dung. Lichens will and do grow on just about everything, natural or manmade. Different species of lichens prefer, or only grow on different substrates. Thus some species will be found on smooth barked trees, some on rough barked and some on only one species of tree. Also some lichens grow on basic rocks while others only grow on acidic rocks and some have particular mineral requirements, thus Acarospora sinopica only grows on rocks with a high iron content. However where ever they grow lichens grow slowly so what ever it is they are growing on, the 'substrate' needs to have been around for a few years. Lichens grow differently at different times in their lives. When young and very small they grow slowly, then once they are reasonably well established they grow much more quickly, obviously when they are dying, for what ever reason they grow more slowly again, or not at all. Lichens grow by extending their thallus outwards, from either its tips or edges. They grow very slowly, some species more slowly than others. Rates of growth can vary from 0.5mm per year to 500mm per year. Their slow growth rate equates with their long life. However the question "How long does a lichen live?" is difficult to answer. The reasons for this are twofold. Firstly because they can reproduce vegetatively, and because any part of the thallus that becomes detached from the main plant can continue growing as new part of the same plant (genetically they are the same individual) it is hard to define the limits of an individual lichen. Secondly, in some cases, when two members of the same species meet they simply merge together to become one plant, again this make identifying an individual lichen difficult. Interestingly not all lichens respond to meeting another member of their species in this way, in some cases they fight for their own individuality. This also occurs between different species and you can often see a mosaic of lichens on a rock all sharply defined by black lines where their individual borders are demarcated. In theory then, some lichens are immortal, and some famous Ascomycetes hold to the truth of this theory. Certainly they can live for a long time and their lives can often be measured in hundreds rather than tens of years. Lichens live all across the world, in Antarctica they can be found living just below the surface of rocks, in deserts, providing there is a permanent substrate they can be found surviving the hottest sun, they can also be found in rock pools on the sea shore and on the roofs of our buildings. Lichens survive in an extremely wide range of temperatures. They have been known to survive temperatures as low as -190C for several hours and as low as -78C for several days. Going to the other extreme they can also survive temperatures as high as 100C if they are dried out, and even when moist temperatures of 40C-50C do not worry them. However because they depend on their Algal partners to photosynthesise in order to obtain energy for growth all lichens need light. There are therefore no subterranean

or deep cave dwelling lichens. Generally speaking lichens like areas where their is plenty of light, such as the exposed surfaces of alpine rocks, and the rooves of our houses...
Like all plants lichens like water, and most of them like a regular supply of it. Optimum humidity fro growth is between 40% and 70%. However some species can survive for up to 9 months without water and obviously those that live in rockpools or streams and ponds survive, and even need constant moisture. Lichens have no special water storage organ, however they can trap and hold for a short while a considerable amount of water in their thalli. This can amount to initially 300 times their dry weight. During their growth lichens tend to absorb and store metallic ions in their thalli. It is unknown quite why they do this or what benefit they derive from it. However it is known that some lichens can tolerate much higher concentrations of metals than other plants or fungi. They also have a high tolerance for radioactivity and can be the first organisms to colonise, or the longest to survive in areas of high radioactive contamination. Lichens produce a strange group of various metabolic biproducts called 'Lichen Products'. These include esters and organic acids and are produced, or at least stored, externally to the fungal and algal cells. They occur in a crystalline form. There are over 350 'Lichen Products' currently known to science, nearly all of which are totally unique to lichens. Exactly what their use is to the lichens remains a mystery, however they are often responsible for giving lichens their attractive colours and may serve to protect the lichen from slugs, snails, psocids and caterpillars, all of which feed on lichens. They are useful to man in the identification of similar looking species, though it may be that some species produce different 'Lichen Products' in different habitats so their taxonomic use is limited.

We can use lichens to now the quality of the environnement

Lichens can be used for many different things:
- From lichen substances drug stores can make antiobiotics.
- Some lichens make feed for plants for example nitrogen.
- Lichens are homes for insects for example spiders.
- Lichens can be used as a natural tint to color wool.
- People eat lichens, but only some sorts because a few are poisonous.
- Lichens can be used as indicator for the pollution in the air, they can tell us if the air is clear.

We like to tell more about the last point of the enumeration :
In 1976, Hawksworth and Rose expose in Britain and Europe that lichens were recognized as potential indicators of air pollution. Since their exposure lichens have a very great influence, at air pollution studies. Because of their sensitivity to pollutants, for example sulfur dioxide (SO_2), sulfur (S) and radioactive elements. Lichens show varying degrees of sensitivity to pollution, because some sorts of lichens grow only were it's a highly polluted and some sorts where no pollution is. Scientist can use the differences of the sensitivity of lichens as a bio-indicator for pollution. In some cases the presence or absence of lichens is recorded and there at different times in the past. At these recording there are prominent differences at the species of lichens from the past until now. The conclusion of this phenomenon is that the quality of the air is changed.
In the 1970's studies in Europe were able to create a plan of 10 zones were the pollution is different. There are indicator species for each zone, these are varying form highly polluted zones to unpolluted zones. At the first zone there were no lichens, the second contained algae only, the third zone contained Hypogymnia physodes and Parmelia caperata. The last zone contained rare species like Usnea articulata.
The colouring and patchiness in the centre of the thallus is also an indicate for the pollution.

In the table you can see the different species of lichens at the different zones of pollution

High polluted	Moderate polluted	A little bit polluted	Minimal or no polluted
Hypogymnia physodes	Evernia prunastri	Parmelia caperata	Usnea subfloridana
Xanthoria parietina	Foraminella ambigua	Grahis scripta	Parmelia perlata
Lecanora dispersa	Lecanora chlarotera	Bryoria fucescens	Degelia plumbea