Op-Ed

Why Our Urban Trees Are Dying

- Andrew Goldsworthy, PhD

"Electricity is carried in living organisms by ions."

Introduction

Trees are now dying mysteriously from a variety of diseases in urban areas all over Europe and are also showing abnormal photoperiodic responses. In addition, many have cancer-like growths under the bark (phloem nodules) and the bark may also split so that the underlying tissues become infected. All of these can be explained as being a result of weak radio-frequency radiation from mobile phones, their base stations, WiFi and similar sources of weak non-ionising radiation. But first let us look at how living organisms use electric currents that they generate themselves and which perform vital functions in their normal day-to-day metabolism and growth. We will then go on to see how weak electromagnetic fields can disrupt these and bring about many unwanted biological effects.

Electricity in living organisms

Electricity is carried in living organisms by ions (electrically charged atoms and molecules). It is generated using metabolic energy to pump ions through cell membranes, which are thin semi-fluid films made mainly of lipids and protein. This generates an electrochemical gradient (a combination of a voltage and concentration gradient) across the membrane and is a store of energy that can then be used for other purposes. The electrical component of this gradient is called the membrane potential and is typically several tens of millivolts for an external membrane.

The chemiosmotic production of ATP in bacteria

Even simple cells such as bacteria use electricity. Bacteria use energy derived from metabolising their food to pump positively charged hydrogen ions out of the cell through their external membranes to give an electrochemical gradient. These ions are then let in again in such a way that the energy of this gradient is used by an enzyme called an ATPase to generate ATP in a process known as "chemiosmosis". ATP is the main energy currency of the cell and can then be used for a variety of purposes.

Ion co-transport

The energy of the electrochemical gradient is also used by transporter enzymes in the membrane to carry nutrients actively into the cell against a concentration gradient. Transporter enzymes mechanically couple the passive movement of ions down their electrochemical gradient to the active transport of other materials in a process known as ion co-transport, which is the main mechanism for active transport in cells.

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The situation in higher plants

Higher plants get most of their ATP from their mitochondria, which oxidise food materials in the dark, and from photosynthesising chloroplasts in the light. These organelles were derived from bacteria over a billion years ago, when they were engulfed by and then lived symbiotically with the precursors of animal and plant cells. They still make ATP electrically by chemiosmosis like the original free-living bacteria, but they make some of this ATP available to the plant (or animal) cell.

Plant cells use some of this ATP to pump hydrogen ions out through their own external membranes to give a second electrochemical gradient, which can be used for the active transport of nutrients and other materials into or out of the cell by ion co-transport. It follows that the efficiency of these processes depends on the insulating properties of the cell membrane. If electromagnetic fields make it leak, the energy available to the cell will be reduced and it will not function or grow so well.

Cell polarity

The membrane potential also helps to generate a voltage between the apex and base of the cell, which gives rise to physiological cell polarity. Cell polarity makes one end of a cell different to the other and is determined electrically. For example, in a tip-growing cell, positive ions are pumped out over most of the cell surface to generate the membrane potential, but are let back in again, mostly at the growing tip, which has the greatest demand for energy. This makes the outside of the cell at the tip slightly negative to the outside of the rest of the cell. This is the trans-cellular potential, which is measured as the voltage between the tip and base of the cell. It is typically about one millivolt, but is enough to move differently charged materials electrophoretically to different places along the cell's axis. This makes the two ends of the cell physiologically different and helps to create and maintain cell polarity.

Polarity in tissues

When polar cells divide, the daughter cells usually retain the same polarity so that, if they give rise to a column of cells, such as in the trunk of a tree, the daughter cells are electrically in series so that their voltages add up. By placing electrodes at different levels up the tree trunk we can measure relatively large voltages that correspond to the sum of the voltages generated by the intervening cells.

However, it isn't quite as simple as this because of the complex structure of the tree. For example, the cambium gives rise to horizontal columns of cells as it divides to increase the girth of the tree. Also, there may be variable voltages between different parts of the tree as their cells use ion currents to absorb nutrients. Nevertheless, the voltages that we measure between different parts of the tree are a reasonable measure of its physiological activity. I will say more about this later.

Cell membranes

As we have seen, plants make extensive use of direct currents (DC) for a variety of purposes, but they do not use alternating currents (AC). In fact, artificially applied alternating currents are harmful. Suzanne Bawin and her co-workers discovered this in the 1970s when they found that weak electromagnetic fields could remove calcium ions from the cell membranes of animal brain tissue. These calcium ions are important because they are positively charged and help to bind together the negatively charged molecules that make up most of the membrane, rather like cement binds together the bricks in a wall. If some of these calcium ions are removed by alternating fields, the membranes will be weakened, become more inclined to leak, and this can produce a variety of biological effects.

One of the effects is to partially short-circuit the membrane potentials of individual cells. This would make the production and use of its energy less efficient, leading to poor growth and loss of vigour. Also, by its likely effect in reducing the trans-cellular potentials, it could disrupt the orderly polar growth of tissues and lead to the production of disorganised cancer-like structures.

However, the most serious effect is on the leakage of materials from lysosomes (in animals) and vacuoles (in plants), both of which contain toxic materials and digestive enzymes normally used to digest and recycle waste. These enzymes include DNase, which destroys DNA, and it has already been shown many times in animal tissue cultures that just a few hours exposure to mobile phone radiation can shatter their DNA into fragments. This could lead to mutations, loss of cellular function and possible cell death. The same may be true for plants and trees.

Weak alternating fields are more effective than strong ones

When people tried to measure the field strengths that released calcium from cell membranes, they discovered that it occurred only within narrow ranges of signal strengths (amplitude windows) above and below which there was little or no effect.

We can explain this with a simple analogy. Imagine trying to harvest ripe apples by shaking the tree. If you do not shake hard enough, nothing happens. If you shake very hard, all the apples fall off. But somewhere between the two, if you shake it with just the right strength (amplitude of shaking) only the ripe ones fall off.

Now let us apply this to cell membranes, which are made of negatively charged components bound together by positively charged ions, of which calcium with its double positive charge is the most important. There are also other ions such as potassium with only one positive charge, but these are less effective. When an alternating field is applied across the membrane it tries to vibrate in time with the field, with the negative membrane components moving in one direction and their positive ions trying to move in the other. If the field is very weak, nothing much happens. If it is very strong, all the ions bounce on and off the membrane in time with the field and there is no overall change in the balance of the ions involved. However, somewhere between the two, there is an "amplitude window" where the field is only strong enough to remove the calcium ions because of their double charge. Their place is then taken by less affected ions with only a single charge, such as potassium. As a result, more and more calcium is removed with each cycle of the alternating field until the membrane is weakened sufficiently to leak and produce a biological effect.

Evidence from the biological effects of "electronically" conditioned water

Electronic water conditioners are now widely used to remove lime scale from plumbing. They change the physico-chemical properties of water and impurities in it to make it more attractive to calcium ions and enable it to remove the lime-scale. They work by applying very weak pulsed electromagnetic fields to the water from antennas wound around the supply pipe. We used it to test the hypothesis that it could produce biological effects similar to the direct application of electromagnetic fields by removing calcium from cell membranes.

After conducting many experiments on both yeast and higher plant seedlings, we concluded that it really does produce similar biological effects. However, exactly what happened depended on the time for which the water had been conditioned. Irrigation with water conditioned for less than half a minute stimulated the germination and growth of wheat seeds, but the growth stimulation did not last long and the untreated controls soon caught up. However, water conditioned for longer inhibited growth from the outset. A possible explanation for this is that the weakly conditioned water (conditioned for less than half a minute) causes minor damage to cell membranes, which activates repair mechanisms, including the synthesis of enzymes and materials normally needed for growth. However this can only occur for a limited time because the resources needed become exhausted, the growth stimulation stops and the untreated controls catch up. Arguably, the more strongly conditioned water does so much damage that the initial growth stimulation does not occur and we see only the inhibition. This dual effect is quite common with direct exposure to electromagnetic fields. Short exposures seem to stimulate growth but longer exposures inhibit it. This could be what is happening to our trees to cause bark crack and phloem nodules.

Cracks in the bark

If growth is initially stimulated by electromagnetic fields, then we might expect the tissues that are already programmed to grow to respond first. These would include the cells of the cambium, which normally divide to increase the girth of the tree. If this were too rapid, it could cause the bark to split and the cracks could then become infected. So this extra growth may not necessarily be a good thing.

Phloem nodules

These can be explained by using what we know about plant tissue cultures. These are usually made by putting pieces of plant onto a nutrient medium containing high concentrations of growth hormones. This makes them produce large amounts of undifferentiated callus, which can grow indefinitely so long as the hormone supply is maintained. If the hormone concentration is reduced by placing the callus on a medium with less hormone, it may differentiate to give something that looks like phloem nodules, having what looks like vascular tissue surrounded by callus. Could this be happening to the trees? If the electromagnetic growth stimulation involves the production of extra growth hormones, this could stimulate the production of undifferentiated callus in the phloem to form "cancer-like" growths. When the rapid growth stage subsides, less hormone is available and the callus differentiates to form the central vascular tissue characteristic of phloem nodules.

The biological clock

Every living cell in plants and animals has a normally accurate clock mechanism that enables it to tell the time of day so that it can anticipate the arrival of dawn and dusk. It is needed because different enzymes are required during the day to those needed at night. Because enzymes take some time to make, their synthesis must start well before they are needed. The biological clock is therefore like an alarm clock that tells the cell to get ready for its day's work before dawn. As a result, many metabolic processes are coupled to the clock mechanism in preference to the actual change between day and night. This gives rise to circadian rhythms for these processes which can often continue indefinitely, approximately every 24-hours, even under constant conditions.

Radio-frequency radiation interferes with the biological clock

Unfortunately, these circadian rhythms are seriously disrupted by radio frequency electromagnetic radiation. We have seen this happen with the electrical potentials measured in trees at Alphen aan den Rijn and Wageningen. The potentials (which are a measure of physiological activity) followed a 24-hour cycle but faded out in a matter of weeks when radio frequency radiation was applied from a WiFi access point. This is bad news since it means that anything controlled by the clock can never work at peak activity under these circumstances.

One of the most important things controlled by the biological clock is the immune system. The immune system requires quite a lot of energy. In plants, it is normally programmed to become active just before the clock "thinks" it should be day (the subjective day) during which there is normally spare energy available from photosynthesis. In animals, the immune system works best in the subjective night, when the lack of physical activity during sleep normally makes more spare energy available. However, in either case, if the clock is not functioning properly due to electromagnetic radiation, then at no time will the immune system be functioning at maximum activity and the tree or animal will become more susceptible to a whole range of diseases to which it might otherwise be resistant.

Cryptochrome and the biological clock

The effect of radio frequency radiation on the biological clock is probably due to its effects on the pigment cryptochrome, which is an essential part of the clock. Cryptochrome is affected by radio waves because it works by shuffling electrons between two free radicals. Free radicals are magnetic, and this shuffling of electrons between them is affected by both permanent magnetic fields and radio frequency fields. The frequencies responsible are lower than those of microwaves, but can be generated when microwaves are modulated to carry information or speech.

This effect on cryptochrome was first discovered by Ritz and his co-workers in 2004 in birds (robins) that use its sensitivity to permanent magnetic fields to navigate using the Earth's magnetic field. They found that the birds became unable to orient themselves for navigation when exposed to a wide range of radio frequencies. If this is true for animal navigation, it is probably also true for its role in timekeeping and circadian rhythms will also be disrupted. We have already seen this in human beings. People living too close to mobile phone masts frequently report poor sleep at night and tiredness during the day, probably because their circadian sleep/wake cycle has been either disrupted or its amplitude reduced, just as we have seen in our trees.

Effects on the shedding of leaves

A more obvious effect of radio waves on the biological clock is on the shedding of leaves and fruit in some trees. This is normally a photoperiodic response to the short days of autumn, with the day-length being measured by the biological clock. An increasing number of trees are now failing to shed their leaves and/or fruit at the proper time and they may even remain attached throughout the winter. Oak and beech seem to be particularly badly affected, but it happens with other trees too. This is an indication that the biological clocks and circadian rhythms of these trees are no longer functioning properly, and it is a reasonable prediction that their immune systems, which are also coupled to the clock, are also not functioning properly. Such trees can be expected to become more susceptible to disease and may soon become unhealthy and die. Similar effects on animals and humans are to be expected.

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Suggestions for further reading

Details of the chemiosmotic production of ATP and ion co-transport for the uptake of nutrients can be found in almost any good biochemistry text book.

More on the effects of electromagnetic fields on plants can be found in a Chapter 11 by A Goldsworthy in "Plant Electrophysiology; Theory and Methods. Ed. AG Volkov, Springer 2006.

More on circadian rhythms can be found in "Introducing Biological Rhythms" WL Koukkari and RB Sothern, Springer, 2006.

Effects of radio waves on cryptochrome can be found in Ritz et al. Nature 429 13th May 2004. pages 177-180.

Effects of radio waves on humans: http://tinyurl.com/34gvn29

Effects of conditioned water on yeast: A Goldsworthy et al. Water Research 33, 1618-1626 (1999).

Andrew Goldsworthy was born in 1939. After a conventional Grammar School education he obtained a First Class Honors Degree in Botany followed by a PhD for research into plant physiology and biochemistry at the University of Wales. He went on to lecture at Imperial College London, where he spent the rest of his career. He has had many teaching and research interests, ranging from the biochemistry of photorespiration to the biology of space flight. He retired in 2004 but remains as an honorary lecturer. He was also a scientific advisor to the European Space Agency and is currently a scientific advisor to several European charities concerned with the environment and electromagnetic fields, including the Bio Electromagnetic Research Initiative, the Radiation Research Trust, and Electrosensitivity-UK. He has always had a strong interest in how living organisms use internally-generated electric currents to control their growth and metabolism, and in their disruption by externally-applied currents and fields. In his retirement, he pieced together nuggets of information from a wide range of scientific journals and created simple layperson's explanations of how weak electromagnetic fields affect us all. The first of these can be found at http://tinyurl.com/2nfujj. The present article was submitted at the request of the Canadian House of Commons Standing Committee on Health for a hearing on April 29th 2010 on the biological effects of microwave radiation".