ROTHAMSTED RESEARCH

UK Environmental Change Network

The U.K. Environmental Change Network

Rothamsted

Physical and Atmospheric Measurements

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The First 20 Years....

First Published 2014

Revised Edition 2015

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Edited by: Dr. Andy Macdonald and Prof. Keith Goulding

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ISBN 978 0 9564424 1 3

From left to right
1. ECN Automated Weather Station (1993 to 2013) at Rothamsted © Tony Scott, Rothamsted Research
2. Precipitation Chemistry – bulk rainwater collector © Tony Scott, Rothamsted Research
3. NO2 Diffusion Samplers (Met Station) © Tony Scott, Rothamsted Research
4. Soil Solution Samplers being pumped down by hand © Tony Scott, Rothamsted Research
5. River Ver flowing through Flint Field on the Rothamsted Estate© Tony Scott, Rothamsted Research





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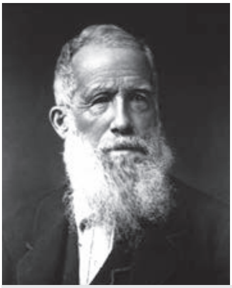
Introduction

Rothamsted Research was established as an agricultural research centre by John Bennet Lawes and Joseph Henry Gilbert in 1843.

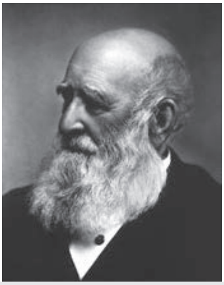
It is home to the oldest continuing agricultural field experiments in existence. These, so called "Classical Experiments", are now a National Capability supported jointly by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Lawes Agricultural Trust. Eight of the Classical Experiments continue today. Two of the best known of these are the Park Grass Hay Experiment (est. 1856) and the Broadbalk Wheat Experiment (est. 1843).

Park Grass

Broadbalk



Sir John Bennet Lawes



Sir Joseph Henry Gilbert

Initially, experiments focused on the effects of mineral fertilisers and organic manures on crop production and soil fertility. Yields were recorded each year and plant and soil samples were archived for future use. Meteorological variables were also recorded; rainfall has been recorded since 1853 and temperature since 1873. More recently, other weather variables together with wet and dry atmospheric deposition and insect abundance have also been monitored.

It was largely due to the long-term experiments, together with their associated datasets and archived samples, that Rothamsted joined the UK Environmental Change Network (ECN) at its inception in 1992. The network is a multi-agency programme, supported by fourteen independent government departments and agencies. Rothamsted is one of twelve terrestrial sites that cover a range of ecosystems including lowland grassland, arable agriculture, woodland/forest and upland moorland/mountain. The scientists at these sites collect physical, chemical and biological data using well defined and agreed protocols (http://www.ecn.ac.uk; Sykes, 1996) for a range of variables (Table 1), which have been identified as key environmental indicators. A central coordination unit (CCU), based at the Centre for Ecology and Hydrology (Lancaster), manages the network and archives comparable datasets for each site. In addition, the Rothamsted Long-term datasets are accessible through the electronic Rothamsted Archive (e-RA), which contains yields (c. 1843 to present) of some of the main classical experiments together with some plant and soil nutrient data and weather data. These datasets are freely available to the scientific community who wish to study the causes and effects of environmental change.

Table 1. Terrestrial Measurements

Physical and Chemical (Abiotic)	Biological (Biotic)
Physical Measurements Manual Meteorological Recording Automatic Weather Station	**Vegetation Measurements** Vegetation Survey: Montane, Grassland, Moorland, Woodland, Arable
Chemical Measurements Precipitation Chemistry[1] Atmospheric Chemistry – NO_2 Soil Solution Chemistry[1] Soil Analysis[2] Surface Water Chemistry[1] 1 Na^+, K^+, Ca^{2+} ,Mg^{2+}, Fe^{2+}, Al^{3+}, NO^{3+}-N, NH_4^--N, PO_4^{3-}-P, SO_4^{2-}-S, Cl^+, DOC, TSN, Alkalinity, Conductivity and pH. 2 *† Moisture, *† pH; Exchangeable cations (*†) - Acidity, Na, K, Ca , Mg , Mn, Al. Total (*†) - N, P, S, C, $CaCO_3$, Pb, Zn, Cd, Cu, Hg, Co, Mo, As, Cr, Ni. Extractable (†) - Fe, Al, P.	**Insect and Animal Measurements** Moths Butterflies Spittle Bugs Ground Beetles Spiders Frog Spawn Common Bird Census Rabbits Bats

This booklet gives a brief overview of the physical and chemical measurements that are routinely measured at Rothamsted, as part of the Long-term Experiments National Capability (LTE-NC) and the United Kingdom Environmental Change Network (ECN).

Rothamsted Estate and the ECN Target Sample Site

Rothamsted is located about 35km north of London, UK (51° 48' 34.44" N, 0° 21' 22.76" W). It covers about 330 ha, all of which is included within the Rothamsted ECN site (Figure 1). The estate contains several ecosystems, including managed arable and grassland fields, naturally regenerated and semi-ancient woodland and the river Ver. It is a rural area within an urban landscape, surrounded by the town of Harpenden to three sides and the village of Redbourn on the south-west side. The larger conurbations of Luton, St. Albans and Hemel Hempstead, together with the M1 motorway and London Luton Airport, are within an eight mile radius. The Park Grass Experiment is the principal target sample site (TSS) for the majority of the ECN protocols at Rothamsted. This experiment is widely acknowledged to be the oldest continuing agro-ecological experiment in the world; it is recognised internationally as an important site for long-term studies on biodiversity and ecology. The experimental plot on Park Grass of most interest to the ECN, in relation to physical and atmospheric inputs is Plot 3, Section d (Plot 3d). This plot receives no inorganic or organic inputs apart from atmospheric deposition.

A recent study of ecosystem services, based on the Millennium Ecosystem Assessment of 2005, covering eleven of the twelve ECN terrestrial sites, showed that Rothamsted, a lowland agricultural site, is more akin to the woodland sites of Alice Holt and Wytham (Dick et al, 2011). This is primarily due to its cultural benefits with numerous footpaths/bridleways crossing the estate. The tranquillity of the rural landscape at Rothamsted, which includes fields and woodland with a variety of flowers during spring and summer together with arable crops and a 17th Century Manor House, draws people from the local area to walk, run, cycle and horse ride. Rothamsted encourages such interaction with the local community, especially schools, through its knowledge exchange and public engagement activities. These include mini-beast safaris, fungi foraging and open weekends.

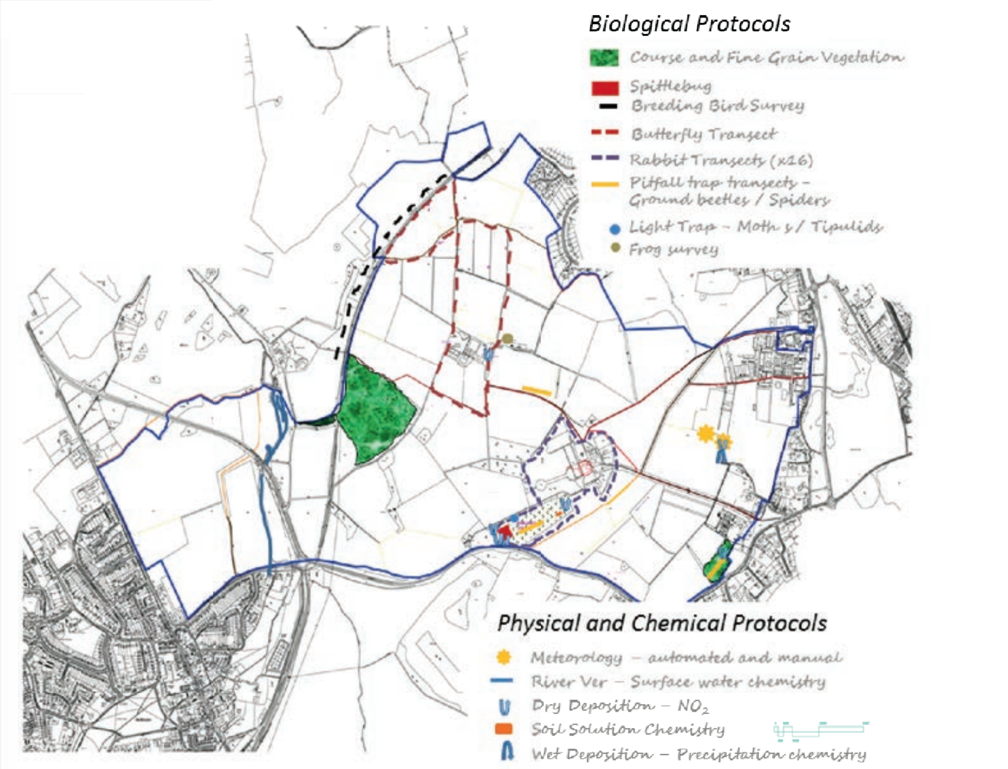


Figure 1. Schematic map of the Rothamsted Estate with Harpenden (East) and Redbourn (South-West)

— Bridleway; — Footpath; — Estate Border; Park Grass Experiment – Target Sample Site

Lawes and Gilbert understood the importance of weather for crop production; consequently they began measuring several important climate variables to complement their work on the Classical Experiments. In 1852, they constructed a rain gauge measuring one thousandth of an acre (4.04 m²) (Figure 2a) to collect and accurately measure rainfall. In addition, they installed a rain gauge with a five inch diameter collector. In 1870, they constructed three drain gauges containing undisturbed soil to depths of 20, 40 and 60 inches to see how much rain percolated through the soil to differing depths; the gauges also covered an area of one thousandth of an acre. These four gauges are still measuring rainfall and drainage, although the methods of measurement have changed. In 1948 the five inch diameter rain gauge was replaced with a five inch diameter copper gauge of Meteorological Office standard within a turf wall (Figure 2b).

Figure 2. (a) The one thousandth of an acre rain gauge with drain gauges behind

Figure 2. (b) Turf wall enclosure with five inch cylindrical rain gauge (centre) and new aerodynamic ARG100 tipping bucket rain gauge

As new equipment became available for measuring different weather variables, scientists added them to the weather station (Table 2), thereby increasing the range of variables monitored. In 2004 the Rothamsted Meteorological (Met) Station was fully automated with electronic sensors.

As part of the methods to ensure compatibility across the twelve ECN terrestrial sites, each site was equipped with an automated weather station with identical instrumentation (ECN AWS) (Figure 3). Installation of the ECN AWS at Rothamsted occurred in 1993; hourly and daily data have been collected from this date.

Table 2. Weather Instruments introduced onto the Met Station

Variable	Year of 1st measurement
Rainfall using 5" rain gauge	1853
Rainfall using 1/1000th of an acre rain gauge	1853
Wind Direction	1853
Drain Gauges	1870
Maximum Air Temperature	1878
Minimum Air Temperature	1878
Sunshine Hours	1890
Grass Minimum Temperature	1909
Wind Force	1915
Dry Bulb Temperature	1915
Wet Bulb Temperature	1915
Earth Temperature at 30 cm depth	1915
Solar Radiation	1931
Soil Temperature under bare soil at 10, 20, 30 cm depths	1931
Soil Temperature under grass at 10, 20, 30 cm depths	1931
Earth Temperature at 100 cm depth	1945
Run of Wind at 2 m	1946
Earth Temperature at 50 cm depth	1948
Wind Speed at 10 m	1960

Figure 3. (a) ECN AWS instrument mast with temperature screen (wet and dry bulb); radiation (global, net, albedo ground and albedo sky); wind (speed and direction) sensors mounted. Below ground are temperature sensors at 10 cm (under bare soil) and 30 cm (under grass); soil moisture probe at 20 cm. (b) ECN AWS tipping bucket rain gauge (foreground)

The weather records from the Rothamsted Met Station and ECN AWS are invaluable to help understand the effects of climate on crop growth, yield and diseases, as well as insect behaviour. The weather records at Rothamsted have revealed dramatic changes in both temperature and rainfall over the last twenty-five years, especially in the first twelve years of the new millennium.

Temperature

The Rothamsted meteorological data have shown that the annual mean air temperature has fluctuated considerably between 1878 and 2012. However, when the variation in annual temperature is smoothed using five year means (Figure 4) it is apparent that air temperatures have risen sharply from 1987 to 2007, but over the last five years temperatures have become more variable than in the previous twenty-one years, with annual mean temperatures ranging from 9.01°C in 2010 to 10.82°C in 2011.

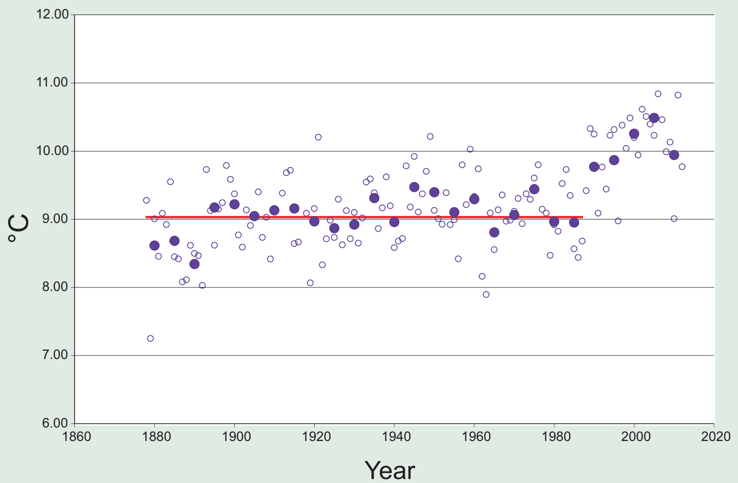


Figure 4. Annual mean air temperature (○) at Rothamsted, 1878 to 2012. Five year means (●) showing increase in annual mean temperature over the last 25 years, with mean air temperature 1878 to 1987 (—).

The seasonal mean air temperatures (Table 3) indicate that the warmest Spring (10.4°C, 2011), Summer (17.8°C, 2003), Autumn (12.8°C, 2006) and Winter (6.19°C, 2007) at Rothamsted have all been recorded in the last decade. The warmest year on record was 2006, with an annual mean air temperature of 10.84°C. Daily air temperatures are considerably more variable; the highest temperature recorded at Rothamsted was 35.6°C in August 2003. The lowest temperature recorded was -17.0°C in December 1981; even lower than the -16.7°C recorded in January 1963.

Table 3. Seasonal Mean Air Temperatures

	Winter (Dec-Feb)	Spring (Mar-May	Summer (Jun-Aug)	Autumn (Sep-Nov)	Annual (Jan-Dec)
Mean Maximum Air Temperature					
Warmest	9.01	16.41	24.15	16.45	14.89
Coldest	1.54	10.37	17.93	11.10	10.79
Year (Warmest)	*1899*	*1893*	*1976*	*2006*	*2003*
Year (Coldest)	*1963*	*1879*	*1922*	*1952*	*1879*
Mean Minimum Air Temperature					
Warmest	3.42	5.81	12.51	9.23	7.11
Coldest	-4.35	1.84	9.27	3.70	3.73
Year (Warmest)	*2007*	*1999*	*2006*	*2006*	*2006*
Year (Coldest)	*1963*	*1887*	*1922*	*1919*	*1887*
Mean Air Temperature					
Warmest	6.19	10.40	17.78	12.84	10.84
Coldest	-1.41	6.24	13.60	7.45	7.27
Year (Warmest)	*2007*	*2011*	*2003*	*2006*	*2006*
Year (Coldest)	*1963*	*1887*	*1922*	*1919*	*1879*

Annual mean rainfall data mentioned in the following text comprises data from the 5" manual rain gauge (1853 to 2003) and the ECN AWS tipping bucket rain gauge (2004 to 2012) (Figure 3) . Both gauges are cylindrical in shape.

Table 4. Monthly, Annual and Seasonal Record Rainfall Totals (mm)

	December	January	February	March	April	May	June	July	August	September	October	November	Annual
Wettest	190.9	136.7	122.5	129.2	154.2	132.8	159.4	167.2	164.5	194.5	198.7	192.4	*978.4*
Driest	4.7	8.1	0.9	1.1	2.2	1.5	2.5	4.1	1.7	0.9	1.1	4.0	*380.1*
Year (Wettest)	1914	1988	1900	1979	2012	2007	2012	1855	1879	1896	1987	1940	*2012*
Year (Driest)	1853	1855	1891	1929	2007	1990	1925	1921	1947	1865	1947	1867	*1921*

	Winter	Spring	Summer	Autumn
Wettest	393.6	329.9	409.9	396.0
Driest	61.8	36.0	34.2	56.4
Year (Wettest)	*1915*	*1979*	*1879*	*2000*
Year (Driest)	*1992*	*2011*	*1921*	*1978*

At Rothamsted the annual 30-year mean (1981 to 2010) for rainfall is 718.4 mm. The annual rainfall for 2012 (Table 4) was 36% greater than the 30-year mean, with total rainfall in April and June reaching 183% and 205% of the 30-year mean (54.5 mm and 52.2 mm) respectively. Paradoxically, both the driest (2007) and wettest (2012) April on record at Rothamsted were recorded in recent years; only six years apart.

The greatest total annual rainfall at Rothamsted to date was 978.2 mm in 2012; exceeding previous records in 2000 (973.2 mm) and 1903 (948.8 mm). The national water providers declared a drought at the end of March 2012 after two years of below average rainfall; the spring of 2011 (Table 4) was the driest on record with only 36.0 mm for the months of March, April and May. Reservoir and aquifer levels had fallen to unsustainable levels by spring 2012. However, heavy rain fell across the UK in April, June and July 2012 with April and June being the wettest on record at Rothamsted. Total rainfall during these months was 154.2 mm and 159.4 mm respectively.

A comparison of temperature and rainfall across the twelve terrestrial ECN sites, since records began in 1992, shows Rothamsted is the 2nd driest ECN site, with a mean monthly rainfall total of only 57.2 mm, slightly more than Drayton's 54.4 mm. Rothamsted is the 3rd warmest site, with an average monthly air temperature of 10.2°C, slightly less than Alice Holt (10.7°C) and Drayton (10.3°C). These sites are in the south central/south eastern part of England, so it is no surprise that they have greater mean temperatures than the more northerly ECN sites.

Atmospheric Chemistry

Atmospheric pollutants, whether anthropogenic or natural, may have detrimental effects on ecosystems including microorganisms, plants, animals and humans. The main sources for these pollutants (Figure 5) are mainly anthropogenic from intensive livestock production (ammonia, NH_3), energy and heating production (sulphur dioxide, SO_2; nitrogen oxides, NO_x) and motor vehicles (nitrogen oxides, NO_x).

When these primary pollutants react with the atmosphere they produce secondary pollutants as acids (sulphuric acid, H_2SO_4; nitric acid, HNO_3; and hydrochloric acid, HCl respectively) and as particulates and aerosols (sulphate, SO_4; Nitrate, NO_3; and ammonium, NH_4). These primary and secondary pollutants are deposited onto the Earth's surface through wet deposition (precipitation as rain, snow and fog) and dry deposition (direct turbulent deposition over a surface).

The increased burning of fossil fuels (e.g. coal, oil and natural gas) since the beginning of the industrial revolution in the mid eighteenth century, has enhanced emissions of these pollutants in the United Kingdom and parts of NW Europe. In recent times Government legislation implemented since the mid-1950s (Clean Air Act 1956, 1968, repealed 1993; Pollution Prevention and Control Act, 1999) has seen a decrease of industrial and domestic emissions of these pollutants into the atmosphere (RoTAP, 2012).

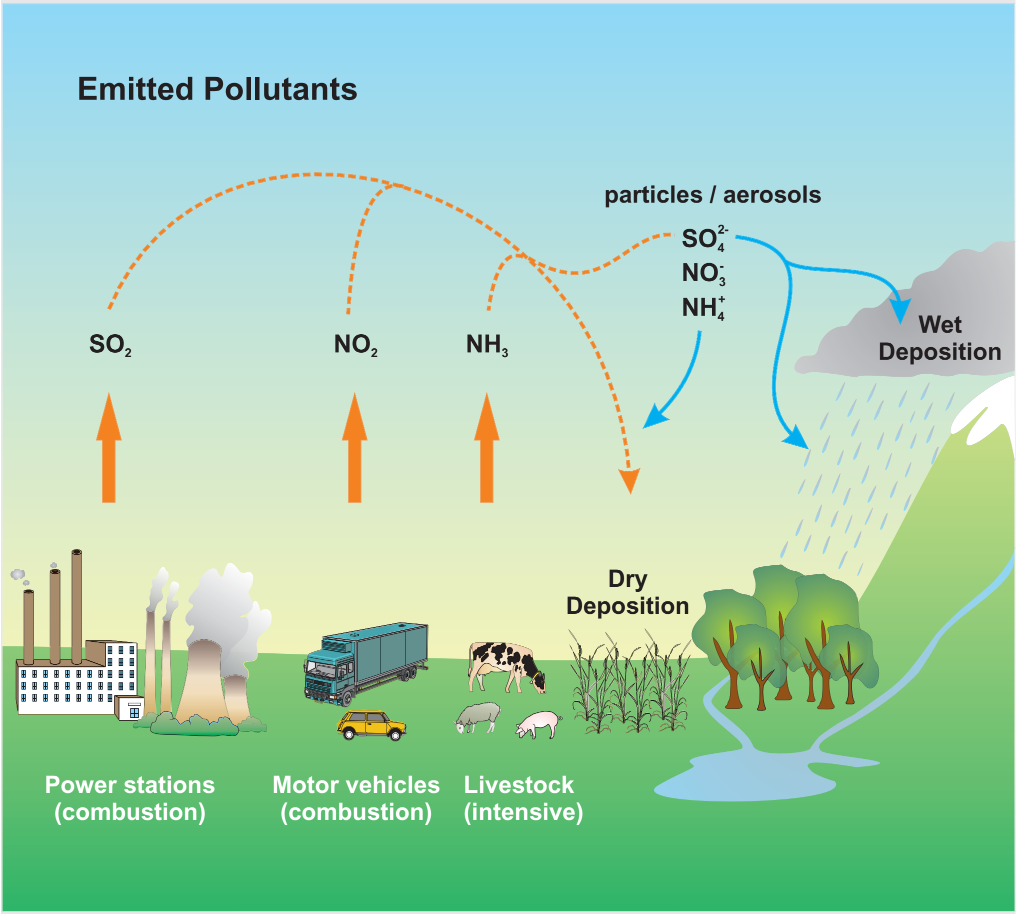


Figure 5. Major processes for the emission and deposition of pollutants (illustration recreated from original by M. Coyle, CEH)

Wet Deposition

Precipitation (rain, snow, fog etc.) is naturally acidic, with a pH of between 5.0 and 5.6. This is due largely to carbon dioxide in the atmosphere reacting with water to produce weak carbonic acid. Acid deposition can be increased naturally through volcanic eruptions emitting SO_2, NO , Cl and VOCs (volatile organic compounds). As already mentioned these pollutants have been further enhanced by the burning of fossil fuels and react in the atmosphere to produce H_2SO_4, NO_3 and HCl respectively. This results in an increase in the acidity of rain water.

Precipitation samples are collected at all ECN sites on a weekly basis and are analysed for conductivity, pH and major ions (Table 1). All sites have seen the pH of rain water increase, except for Hillsborough, Northern Ireland, and the level of major ions associated with acidity decrease (Morecroft et al, 2009). At Rothamsted the pH of precipitation has increased from 4.5 to 5.2 between 1992 and 2012 (Figure 6); a ten-fold decrease in acidity in twenty years.

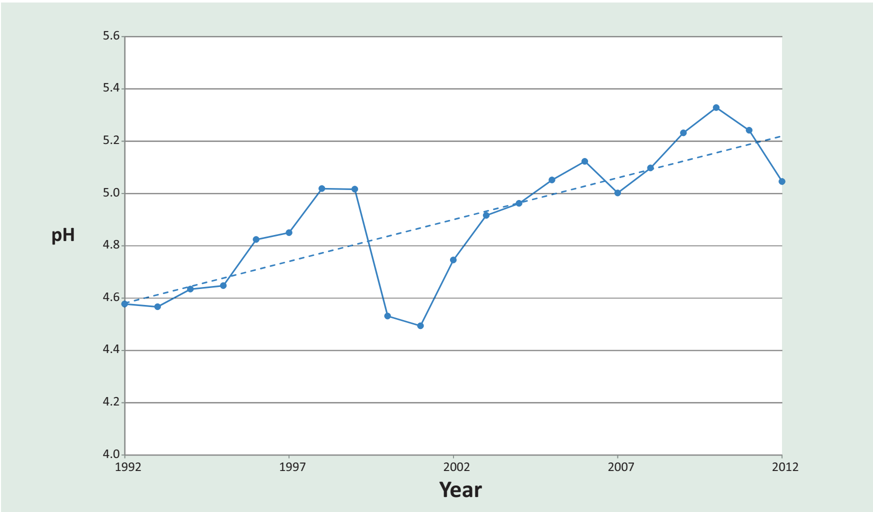


Figure 6. Annual volume weighted mean pH of rainfall at Rothamsted (1992-2012).

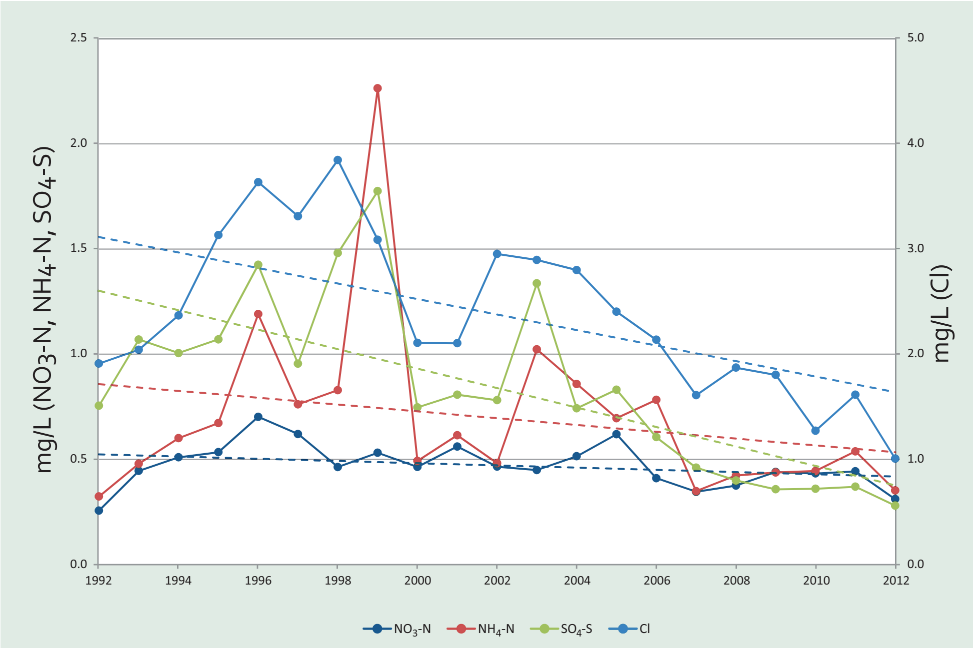


Figure 7. Annual volume weighted mean of concentrations in rainfall collected at Rothamsted.

The precipitation chemistry (wet deposition) results show a decreasing trend in SO_4-S, NO_3-N, NH_4-N and Cl concentrations at Rothamsted (Figure 7) over the last twenty years. Despite the regular inputs of N and S in the fertilisers applied to arable crops grown at this site, this would indicate that the contributions of these fertilisers to local atmospheric deposition are relatively small. Concentrations of sulphur (S), nitrate (NO_3) and ammonium (NH_4), within wet deposition, across the UK have steadily declined. Over a twenty year period, 1986 to 2008, there has been a reduction of approximately 70%, 24% and 35% respectively in S, NO_3 and NH_4 (RoTAP, 2012).

Dry Deposition of Nitrogen

The main sources of atmospheric nitrogen are ammonia (NH_3), from intensive livestock farming and recently motor vehicles with the introduction of catalytic converters (although this has been reduced with the introduction of 3-way catalytic converters), and nitrogen oxides (NO_x) comprising nitric oxide (NO) and nitrogen dioxide (NO_2) from fossil fuel combustion (e.g. power stations, motor vehicles and domestic heating). In 1970 the UK was emitting approximately 2.6 million tonnes NO_x peaking at approximately 2.9 million tonnes in 1989 (Figure 8). This upsurge in emissions was due largely to an increase in road transport. Since 1970 the total emission of NO_x for the UK has decreased by 46% with emissions from power stations decreasing by 49% and that from road transport by 61% (Dore et al, 2008; DEFRA, Statistical release 2012). The large decrease in that emitted from road transport (Figure 8) is due to improvements in fuel quality and the introduction of catalytic converters to petrol vehicles in 1993.

Rothamsted is located in a semi-urban area with the resultant large use of domestic heating and motor vehicles. The fuel used (coal, oil, natural gas, petrol and diesel) for these purposes, almost certainly contributes significantly to the local NO_x emissions.

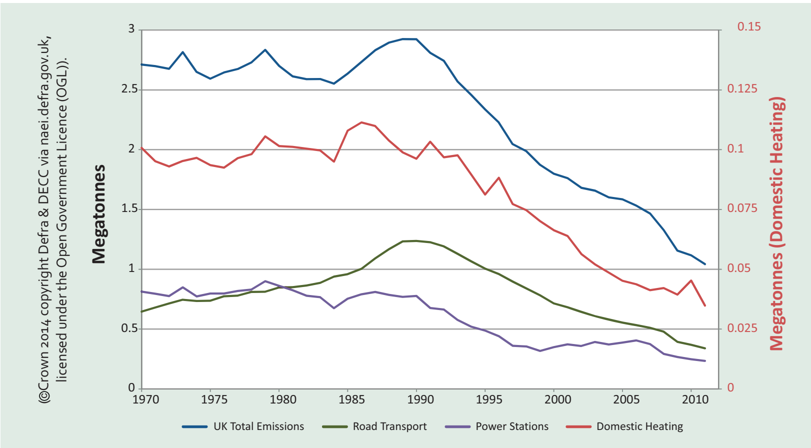


Figure 8. UK emissions of NO_x as NO_2 and that emitted by road transport, domestic heating and power stations

At Rothamsted we measure concentrations of NO_X as NO_2 (which includes NO). The Rothamsted data (Figure 9a and 9b) show seasonal peaks and troughs, year on year, as the demand for fuels increases during the autumn/winter months and declines during spring/summer months. The annual means show that, even though there is seasonal variation, NO_2 concentrations at Rothamsted have fallen by 50% (Figure 9a) from a maximum of 11.64 µg N/m³ (4.4 kg.N.ha^{-1}) in 1996 to 5.87 µg N/m³ (2.2 kg.N.ha^{-1}) in 2012 and that there is a clear downward trend in NO_2 levels. This decrease is in line with national statistics (Defra National Statistical release 2012), with UK NO_x emissions having fallen by 53% (1996 to 2011) and which are predicted to continue to fall.

NO_2 concentrations measured near to the B487 (Redbourn Lane), a secondary but an important arterial road in and out of Harpenden, show that levels are much higher and more variable (Figure 9b). The variability is most likely associated with changes in traffic volume due to weather and school holidays. Also, at peak traffic times, levels of NO_2 will increase as traffic becomes stationary or moves relatively slowly passed the samplers. Mean annual concentrations show that, even near the road, levels have fallen by 26% from 13.92 µg N/m³ in 1995 to 10.26 µg N/m³ in 2012.

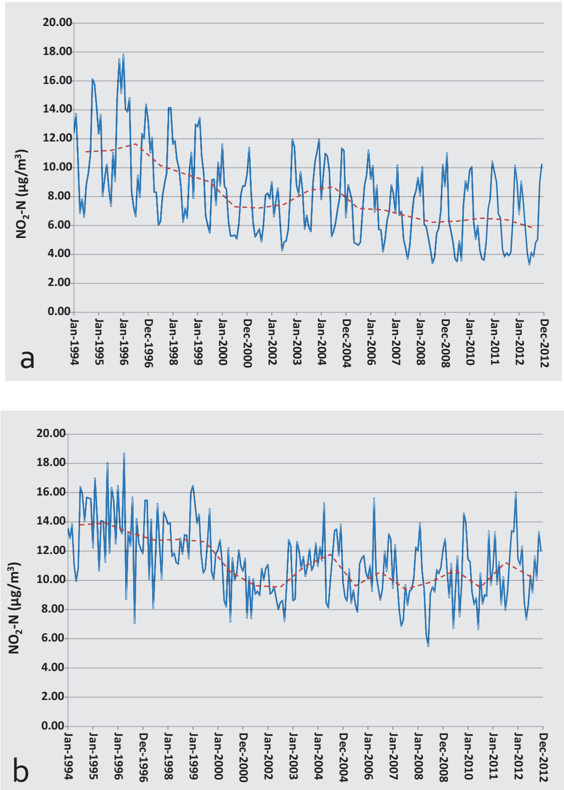


Figure 9. Mean monthly (——) and annual (- - -) atmospheric NO_2 concentrations (µg N/m^3) showing seasonal and annual fluctuation in levels of N measured as dry deposition at a) Rothamsted Met Station and b) near to B487, Redbourn Lane (1994-2012).

Soil Solution Chemistry & Plant Diversity

Changes in climate (e.g. temperature and rainfall) along with the deposition of major ions (wet and dry deposition) can affect the behaviour of soils and therefore plants. Within the soil, microbes play an important part in making the major ions available to plants. They digest dead plant material and release the nutrients back into the soil. The living plants then take up these nutrients in soil solution through their roots. In small quantities these nutrients are used by plants to grow and reproduce (flower and seed). However, in excess they become harmful, in some cases turning soils acidic, which can inhibit certain processes within the plant and soil.

In a six metre square area adjacent to Plot 3d on Park Grass, which also receives no fertiliser or nutrient inputs, porous silica/quartz suction cup lysimeters have been inserted into the soil at depths of 10 cm (shallow) and 50 cm (deep) to allow analysis of the soil solution. Every other week the lysimeters are pumped down to a pressure of -0.7 bar to draw the solution out of the soil, and the following week the solution is collected in and analysed.

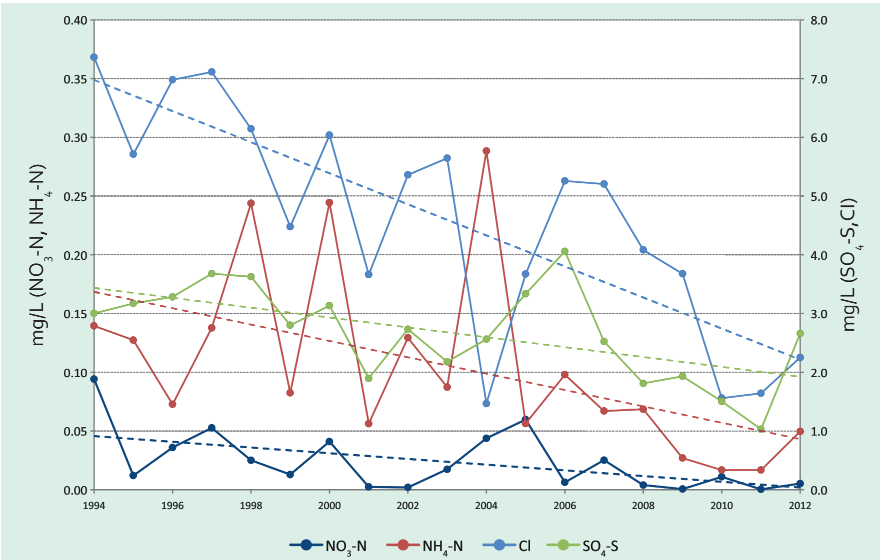


Figure 10. Annual volume weighted means of nitrate-N (NO_3-N), ammonium-N (NH_4-N), sulphate-S (SO_4-S) and chloride (Cl) in shallow soil solution (October to September).

The analyses show that within shallow soil solution, although there is variability in annual concentrations, the overall trend is downwards (Figure 10), reflecting the change in precipitation composition. This trend is also seen in the deep soil solution (not shown).

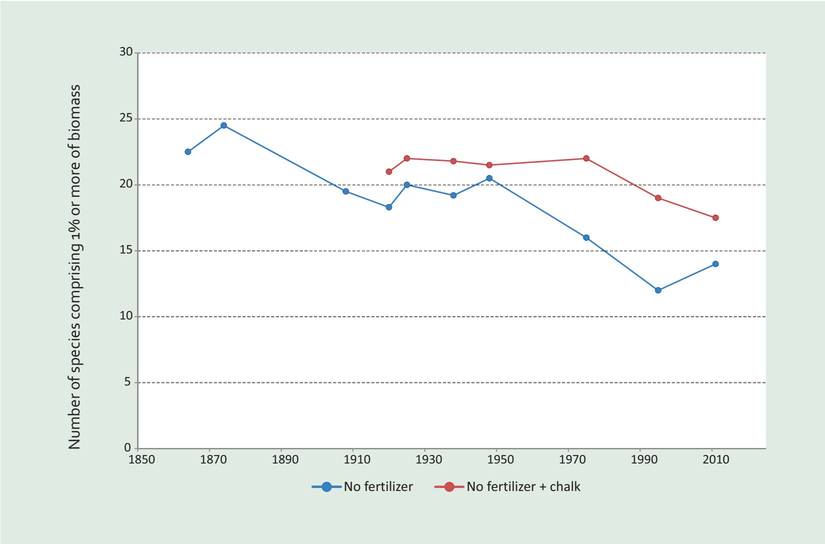


Figure 11. Number of species comprising 1% or more of the total biomass, Plot 3, Section d, of the Park Grass Hay Experiment

Vegetation surveys of Plot 3d show that since the experiment began there has been a decline in the species number comprising one percent or more of the plant biomass (Figure 11). This is probably as a result of increases in atmospheric N concentration and acid rain. However, subsequent decreases in atmospheric N concentration and recent increases in precipitation pH (Figure 6) may help prevent further loss of diversity. The decline in species number can also be counteracted, to some extent, by the application of chalk ($CaCO_3$).

Surface Water Chemistry: The River Ver

The River Ver flows for 12 miles from its source in the Chiltern Hills at Kensworth Lynch, Bedfordshire, to its confluence with the River Colne near to Bricket Wood, Hertfordshire. The upper section of the Ver flowing from Kensworth Lynch to Redbourn is a natural 'Winterbourne', a common feature of chalk streams. Because chalk is porous such streams only flow when the water table is sufficiently high enough for it to break the surface. This usually occurs after sufficient autumn and winter rainfall. Nowadays, with prolonged periods of no or very little rain, there can be years when the River Ver doesn't flow. Where the river passes through Rothamsted land (Flint Field) it flows over topsoil which has been described as a sandy silt loam to silty clay loam, mainly humose and locally calcareous with a subsoil described as flinty sandy silt loam to silty clay loam over flint gravel within 80 cm; mainly greyish and mottled (Avery and Catt, 1995). It has an overall classification by the Soil Survey of England and Wales as argillic, humic, gley soil.

The chalk aquifer of the Ver valley provides drinking water to the surrounding population with extraction from deep boreholes. The section of the Ver that passes through Flint Field has a pumping station at Friars Wash, Flamstead, Herts, 3 km to the North-West in the upper valley, and another at Bow Bridge, St. Albans, 4 km to the South in the lower valley. The pumping station at Friars Wash remains on 'emergency standby' only. It used to pump fifteen million litres of water per day (Ver Valley Society, www.riverver.co.uk) continuously until, in 1992/3, the Ver Valley Society, with other environmental pressure groups, petitioned for extraction to be halted to save the stream and unique local habitat. The pumping station at Bow Bridge was opened in 1964 pumping six million litres per day (ca. 1967).

There was a brief cessation of pumping at Bow Bridge in December 2005 due to the fire and explosion at the Buncefield oil depot, Hemel Hempstead, Hertfordshire. As a precaution against contamination of the local water supply and rivers from the chemicals being used to put out the fire, the Environment Agency (EA) suspended licenses permitting extraction of water from the Ver Valley. In June 2009 the EA lifted the suspension and extraction began again at Bow Bridge.

During the period of suspension the River Ver began to flow again through the Rothamsted Estate and to flow continuously from early March 2007 until it ceased in May 2011 (Figure 12a). However, we cannot be sure whether the cessation of pumping or an above average annual rainfall for the autumn/winter of 2006/2007 (+218.3 mm) or both contributed to the resumption of flow. Prior to this the flow of water in the river was last seen in December 2004. Currently the river is flowing after above average rainfall in 2012 (Figure 12b).

Figure 12. The River Ver flowing through Flint Field in (a) April 2011 and (b) January 2013 following above average rainfall in 2012. These two images show the extreme states of the river when the water table is very low and very high.

When the Ver is flowing water is sampled on a weekly basis and analysed for the same major ions that are measured in precipitation and soil solution (Table 1). The fact that the flow of water in the Ver is not continuous makes it hard to determine how clean the water is and whether pollutants in the river are increasing or decreasing. The analyses indicate that the major ions increase/decrease depending on the depth and flow of the river at time of sampling (Figure 13).

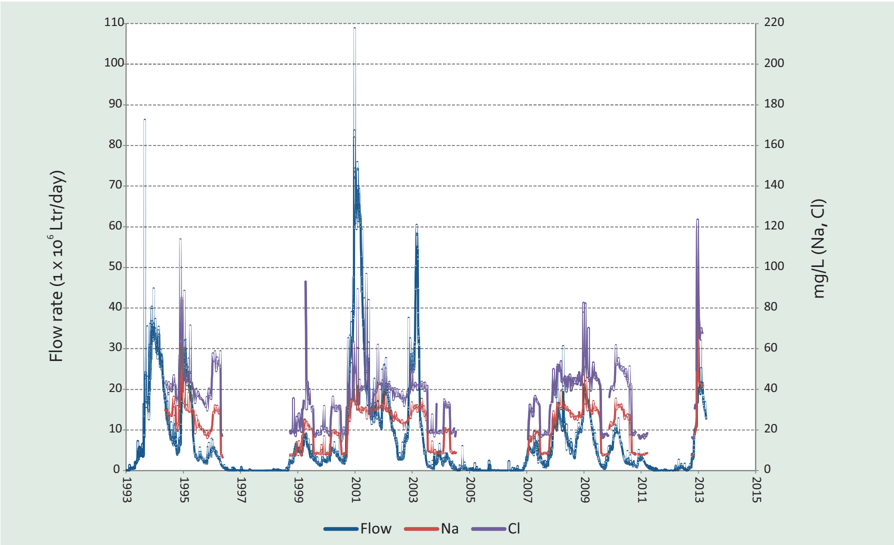


Figure 13. At times of increased flow (Ml/day) the concentration of ions, e.g. sodium (Na) and chloride (Cl), entering the Ver from the surrounding land areas increases (Flow data provided courtesy of the Environment Agency).

Fitting a linear trend line to annual means shows that there is a decrease or no change in ion concentrations (Figure 14).

At present the mineral concentrations measured in the River Ver are below the maximum permitted values (Table 5) for drinking water, as specified by the World Health Organisation (WHO, 2011).

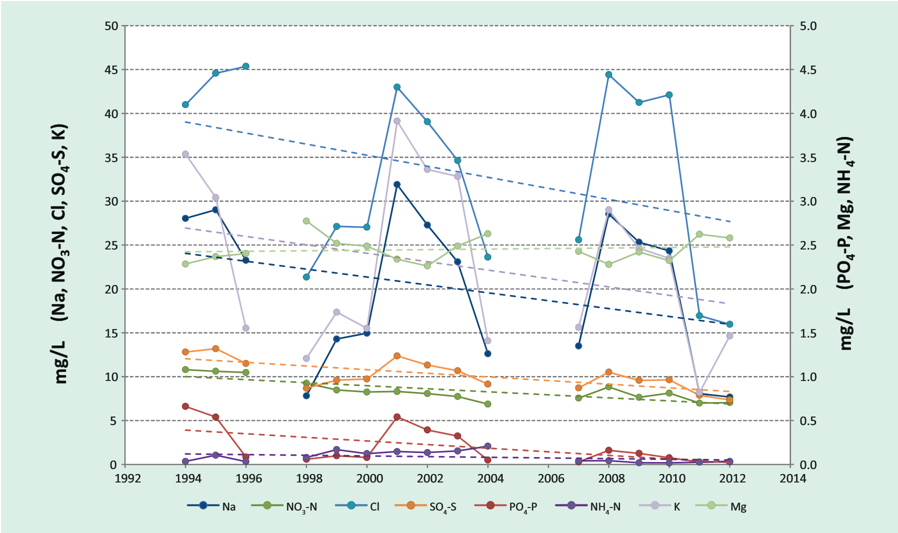


Figure 14. Annual mean concentrations of major ions (mg/L) measured in Ver at times of flow.

Parameter	Permitted Value in Drinking Water
Aluminium (Al^{3+})	200 µg/l
Ammonium-Nitrogen ($NH4^{-}$-N)	125 µg/l
Chloride (Cl^{+})	250 mg/l
Iron (Fe^{2+})	200 µg/l
Nitrate-Nitrogen (NO^{3+}-N)	11 mg/l
Sodium (Na^{+})	200 mg/l
Sulphate-Sulphur (SO_4^{2-}-S)	125 mg/l
Calcium (Ca^{2+})	No Standard
Magnesium (Mg^{2+})	No Standard
Phosphate-Phosphorus (PO_4^{3-}-P)	No Standard
Potassium (K^{+})	No Standard
Hydrogen ion (pH)	6.5 to 9.5
Conductivity	2500µS/cm at 20°C

Table 5. WHO maximum permitted concentrations of the major cations and anions, together with limits for pH and conductivity, in drinking water (Guidelines for Drinking Water, 4th Edition, World Health Organisation, 2011)

Summary

Since the ECN was established over 20 years ago there have been many changes to the environment at Rothamsted. In particular we have experienced extremes in both temperature and rainfall, both indicative of climate change. The major ions in the atmosphere, which are deposited wet or dry, have decreased in concentration following the introduction of government legislation to reduce emissions of harmful pollutants into the atmosphere. This has meant that the pH of rainfall has increased to a level where it is no longer deemed to be acidifying and therefore harmful to nature. The same trends in atmospheric chemistry are seen at the other ECN sites, except for Hillsborough where pH in precipitation still seems to be decreasing. The effect of weather extremes and especially acid rain has changed ecosystems. This is shown on Plot 3d of the Park Grass Experiment where the number of species comprising 1% or more of total biomass has declined over the years, but recent increases in precipitation pH and decreases in nitrogen concentration may help prevent further decreases in species diversity; a topic to be examined in future studies.

Arable

Woodland

Datasets

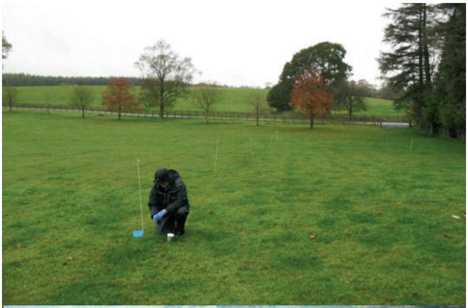
The data presented here represents a small part of the total collected at Rothamsted as part of the work on the Long-term Experiments and the United Kingdom Environmental Change Network. Additional information is freely available to the scientific community and the public via the electronic Rothamsted Archive (**www.rothamsted.ac.uk/eRA**) and ECN Data Centre (**data.ecn.ac.uk**).

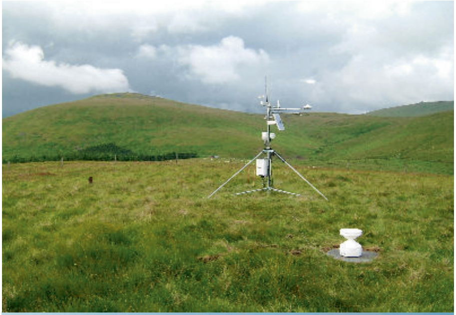
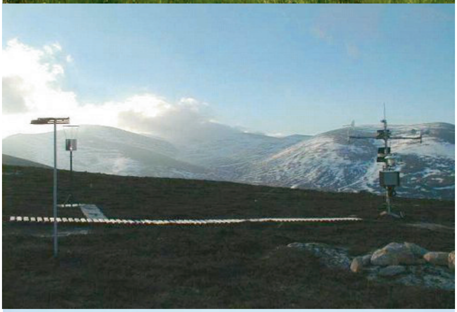
Rothamsted also undertakes the collection of rain water and air samples on behalf of the United Kingdom Eutrophying and Acidifying Pollutants (UKEAP) network. This network consists of the Precipitation Network (Precip-Net), National Ammonia Monitoring Network (NAMN), Acid Gas and Aerosol Network (AGANet) and the NO_2-diffusion tube Network (NO_2-Net). This network carries out atmospheric monitoring that is complementary to the work of the ECN. Summary data for the UKEAP network is available at **http://pollutantdeposition.defra.gov.uk/ukeap.**

Grassland

Energy crops

ECN Terrestrial Sites



Left column :

1. Hillsborough, Northern Ireland © Mel Flexen, AFBINI
2. Wytham, Oxfordshire © Centre for Ecology and Hydrology
3. ADAS Drayton, Warwickshire © ADAS
4. Porton Down, Wiltshire © Defence Science and Technology Laboratory

Middle column:

5. Aerial view of Manor Grounds (Rothamsted) with Park Grass Hay Experiment (left) © Rothamsted Research
6. North Wyke © Rothamsted Research, North Wyke
7. Yr Wyddfa (Snowdonia), North Wales © Cyfoeth Naturiol Cymru - Natural Resources Wales
8. Glensaugh, Scotland © The James Hutton Institute

Right column:

9. Sourhope, Scotland © The James Hutton Institute
10. Cairngorms, Scotland © Centre for Ecology and Hydrology
11. Moorhouse/ Upper Teesdale, Lancashire © Centre for Ecology and Hydrology
12. Alice Holt, Surrey/Hampshire © Forest Research

References

Avery B.W. and Catt J.A. (1995). The Soil at Rothamsted. *Lawes Agricultural Trust*.

Defra National Statistics Release (2012). Emissions of air pollutants in the UK, 1970 to 2011, *Defra*

Dick J., Andrews C., Beaumont D.A., Benham S., Brooks D.R., Corbett S., Lloyd D., McMillan S., Monteith D.T., Pilgrim E.S., Rose R., Scott A., Scott T., Smith R.I., Taylor C., Taylor M., Turner A. and Watson H. (2011). A comparison of ecosystem services delivered by 11 long-term monitoring sites in the UK environmental change network. *Environmetrics; 2**2**, 639–648*

Dore C.J., Murrells T.P., Passant N.R., Hobson M.M., Thistlethwaite G., Wagner A., Li Y., Bush T., King K.R., Norris J., Coleman P.J., Walker C., Stewart R.A., Tsagatakis I., Conolly C., Brophy N.C.J. and Hann M.R. (2008). UK Emissions of Air Pollutants 1970 to 2006**.** *AEA Technology, Harwell, Oxfordshire. Defra Report.*

Morecroft M.D., Bealey C.E., Beaumont D.A., Benham S., Brooks D.R., Burt T.P., Critchley C.N.R., Dick J., Littlewood N.A., Monteith D.T., Scott W.A., Smith R.I., Walmsley C. and Watson H. (2009). The UK Environmental Change Network: Emerging trends in the composition of plant and animal communities and the physical environment. *Biological Conservation, **142**, 2814–2832*

Pollution Prevention and Control Act, Chapter 24, 1999, UK Public General Acts, *HMSO*

Review of Transboundary Air Pollution (RoTAP): Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK (2012), *Prepared by the Centre for Ecology and Hydrology on behalf of : Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland.*

Sykes J.M. and Lane A.M.J. (1996). The UK Environmental Change Network: Protocols for standard measurements at terrestrial sites , *The Stationery Office*.

The Clean Air Act, Chapter 11 (1993). UK Public General Acts, *HMSO*

World Health Organization (2011). Guidelines for Drinking-water Quality, Fourth Edition, *WHO Press*

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Acknowledgements: I would like to acknowledge the work of previous ECN site managers at Rothamsted for their diligence in collecting and analysing samples and quantifying results.

The work of the United Kingdom Environmental Change Network at Rothamsted is part of the Rothamsted Long-Term Experiments National Capability supported by the BBSRC and Lawes Agricultural Trust

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