

Development and Perspective of Soil Survey in the Netherlands

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History

The history of soil survey in The Netherlands has three important phases, each with its own characteristic approach or perspective:

1837 - 1943: the geological approach;

1943 - 1983: the pedological approach;

1983 - present: re-discovery of the soil map.

1837 - 1943: The Geological Approach

This period was recently described by Felix (1995). At the start of the period (1837-1877) various geologists produced maps that described the surface geology. They used lithological legends with descriptions that sound very familiar, e.g. sandy soil, clay soil and peat soil.

The most important contribution came from Dr. Winand Staring. Between 1857 and 1867 he produced the first Geological Map of the Netherlands (1:200,000). The map's legend showed 60 lithological units. In its time it was a very innovative map, as it was the first one to show for an entire country the various unconsolidated Pleistocene and Holocene deposits.

From his geological map Staring derived two other maps: a 'School Map' for educational purposes (1860) and an 'Agriculture Map'. In the 'School Map' the number of lithological units had been reduced to 19. Another very important derived product was a generalised Geological Map at scale 1:500,000.

This map was published in 1877 as part of a national atlas that was also used in schools. This geological map distinguished seven major lithological units, each unit having its own distinct colour.

Between 1877 and 1960 all school children came to learn that yellow stood for sandy, blue for clay, etc.

From 1877 to 1918 no soil maps were produced. However, two groups of researchers contributed to the advancement of soil science: geologists and soil chemists. The geological input concerned knowledge about the composition of rocks and minerals, whereas the soil chemists were interested in soil fertility.

Between 1918 and 1943 a growing distance between geologists and soil scientists seems to have occurred. Geologists and geological maps could not sufficiently answer agricultural questions and soil science stepped in to bridge the gap.

A very important step was the approach to soil survey developed by W.A.J. Oosting. His approach was based on integration of local geology, geomorphology, vegetation and soil forming processes. This landscape-oriented approach would later be adopted by Edelman and become a cornerstone of Dutch soil survey, which is the main output of the next period.

1943 - 1983: The Pedological Approach

De Bakker (1995) has given a description of this period. He distinguishes two important phases in this period which can be described as:

- The physiographic phase;
- The morphometric phase.

During the physiographic phase soil survey went through an exciting period. All early soil surveys concerned areas with Holocene fluvial and marine deposits. The soils in these areas showed clear

relationships with geogenesis, geomorphology (relief), vegetation and land use, which formed the basis of each legend.

The awareness of these 'physiographic' relations formed the clue to the analysis (survey) of the area. Each new survey area was an exciting 'terra incognita', but with the master key of physiographic analysis to unlock it. Consequently, each area finally received its own specific physiographic soil legend.

This phase had various periods and products of national and international importance. The discovery of the importance of soil survey information for agriculture and rural development led to the foundation of a National Soil Survey Institute ('Stiboka') in 1945. Prof. Dr. C. H. Edelman, who had stimulated and guided all early soil surveys, became its first director.

It was also Prof. Edelman who took the initiative to organise the first Congress of the International Soil Science Society after the Second World War in 1950 in the Netherlands. On this occasion he published 'Soils of the Netherlands' (1950), a book containing also a provisional soil map of the Netherlands, scale 1:400,000. This map is the first 'modern' soil map of the Netherlands. Edelman combines the early work of Staring, the lithological units, with 'his' physiographic approach.

To bring the provisional soil map to a conclusion, it was decided to publish a map at scale 1:200,000. Fieldwork was carried out in the years 1952-1954, but the map itself was published in 1965 (Stiboka). In the meantime much more attention was given to soil information, especially measurable profile characteristics and soil classification. In other words, the morphometric phase had begun.

This gives the 1965 map a dual nature: on the one hand it still shows physiographic elements, on the other hand many subdivisions in the legend are based on 'new' variables, such as content of calcium carbonate, texture and % organic matter in clay soils. This dual nature makes the 1965 map the symbolic end of the physiographic phase and a clear indicator of a more morphometric future.

The morphometric phase was triggered by the fieldwork for the soil map, scale 1:200,000. The rapidly increasing knowledge about soils called for more standardisation and co-ordination. The need for a soil classification system also became apparent. In line with international developments a morphometric approach was chosen.

In the physiographic approach geogenesis and landscape development are diagnostic, whereas in

the morphometric approach it is the soil properties resulting from geogenesis and landscape development that are diagnostic. The morphometric approach culminated in a Dutch soil classification system (De Bakker and Schelling, 1966) and a legend for a new systematic soil survey of the Netherlands at scale 1:50,000. The first sheet of the soil map at a scale of 1:50,000 was published in 1964, the last one in 1995.

1983 - present: Re-discovery of the Soil Map

During the 1980s certain developments had considerable impact on soil survey and the use and interpretation of soil survey results (maps and data). These developments were:

1. A marked increase in agricultural production;
2. A deteriorating environment;
3. A growing competition for the limited space of the rural areas;
4. An explosive development in information technology.

The strongly increasing agricultural output was to a considerable degree based on higher inputs of nutrients and pesticides. This caused, amongst others, phosphate saturation of soils, followed by leaching of phosphate to groundwater and surface water, which in turn contributed to eutrophication of these waters and disturbance of aquatic ecosystems.

Another effect was leaching of nitrate to groundwater, with negative effects on its suitability for drinking water. The growing population with its increasing welfare and its new concern for environmental quality, led to new claims on the use and quality of the rural areas and its natural resources.

Recreational use, nature development and concern for biodiversity and water quality all contributed to the introduction of measurable quality criteria for soils and groundwater and to the introduction of legal restrictions on the amount and time of application of manure and fertilisers.

This impressive array of problems and measures stimulated research into the actual soil physical and soil chemical processes governing the fate of nutrients and pesticides in soil, groundwater and surface water. The results of process oriented research, e.g. various models, were quickly applied in a regional context to predict developments or evaluate policy measures aimed at reduction of phosphate saturation, nitrate leaching, etc.

Table 1: Overview of national soil maps

Name	Publication	Scale	GIS-version
Geological map of the Netherlands	1867	1:200,000	no
Geological map of the Netherlands	1877	1:500,000	no
Provisional soil map of the Netherlands	1950	1:400,000	no
Soil map of the Netherlands	1960	1:200,000	no
Soil map of the Netherlands	1964-1995	1:50,000	yes
Soil map of the Netherlands	1985	1:250,000	yes
Generalised soil map of the Netherlands	1986	1:1,000,000	yes

All this new research caused a new and growing demand for soil information:

- Process-oriented models for the description of the transformation of chemical compounds in the soil or for the description of water and solute transport through the soil require process parameters derived from soil profile data through pedotransfer functions;
- Regional environmental studies (nutrients, pesticides, water management) need spatial soil information to describe the initial or current soil status and to derive the above process parameters.

Soon it also became clear that the type of soil information collected so far, and the way in which it was collected, could not produce all the required data or the desired quality of data. As the regular 1:50,000 scale soil survey neared its conclusion, the focus was gradually reset, resulting in:

1. A new programme for upgrading the national soil database;
2. A new programme for the development of an ecological soil survey and land evaluation;
3. The development of new methods for collecting soil data based on spatial statistics (e.g. geostatistics);
4. The development of new methods to transfer existing soil information into new data (pedotransfer rules and functions);
5. The execution of commissioned soil surveys tailored to the needs of the client.

All this could only be realised due to rapid developments in information technology. The development of GIS, process-oriented models and the integration of GIS and models were of overriding importance in this phase.

Present State of Soil Survey

The present state of soil survey has been described earlier (van der Pouw, 1996; van der Pouw and Finke, 1999). The essential facts are that the national

soil survey was completed in 1995 and various national maps of smaller scale were also derived. Table 1 gives an overview of existing national soil maps, including the historic maps reported in the Sections above.

Soil Information at National Level

The core of present national soil information is the 1:50,000 scale soil map. However, before this map was completed there was a need for a more up-to-date small-scale map. Therefore Steur *et al.* (1985) compiled a new map at a scale of 1:250,000. This map was mainly derived by simplification and generalisation of the 1:50,000 soil maps, for which at the time about 70% of the fieldwork had been completed. Other, more detailed soil maps and some additional fieldwork were used to obtain the remaining 30%. Subsequently Steur (1986) produced a generalised soil map at a scale of 1:1,000,000. This map was the basis for the Dutch contribution to the soil map of Europe at a scale of 1:1,000,000 (CEC, 1985).

Upgrading of National Soil Information

The national soil survey at a scale of 1:50,000, which started in the early 1960s, was directed towards collecting and interpreting soil information for agriculture and forestry production purposes. Obviously this systematic information was not capable of meeting the soil information demanded by models and regional studies of a different focus, e.g. leaching of excess nutrients or possibilities for nature development.

The strategy for coping with this problem was twofold:

1. Try to use the existing information as much as possible, using new pedotransfer functions and expert knowledge;
2. Start a new survey programme aimed at upgrading the existing information.

Van der Pouw (1996) reported in some detail about the preparation and execution of the upgrading programme. The main actions are:

1. Revision of groundwater depth classes of the 1:50,000 soil map;
2. Probability sampling of mapping units of the 1:50,000 soil map;
3. Collection of new data.

Revision of groundwater depth classes

The average level of the groundwater table in the Netherlands has fallen during the past decades. In some areas it has fallen 50-100cm (Finke *et al.*, 1998). From the beginning of the national soil survey scale 1:50,000 in the early 1960s the Dutch soil maps not only showed the soil units but also featured groundwater depth classes that indicated the average annual mean highest and mean lowest groundwater table. As a direct consequence of the falling groundwater table, the 'wet' groundwater depth classes on the older map sheets are gradually becoming obsolete. Moreover it was found that some of the earliest map sheets were of poor quality. To combat this situation the following action was taken, in chronological order.

Revision of groundwater table maps

This revision took place for a number of older map sheets using the traditional field approach to surveying groundwater depth classes. This approach leaves the soil boundaries as such in principle unaltered. A typical example of this approach was the revision of a large part of the province of Drenthe.

Entire revision

An entire revision covers all aspects of the map legend, i.e. soil types, groundwater depth classes and special features. Only one map sheet was entirely revised, using the traditional field survey approach.

Development of new methods

While revising groundwater-table maps and the entire revision, it became clear that it was not feasible financially to carry out the remaining revision by the traditional methods employed for the national 1:50,000 soil map. Finke *et al.* (1995) therefore developed alternative methods for revision of the information on groundwater depth class. These methods offer a range from low cost and low reliability of results to high cost and high reliability.

At the high end of this cost range, a grid cell (25x25m²) based remapping method for 1:10,000 scale maps was designed that produces maps of various aspects of groundwater table dynamics. One of these aspects is the traditional groundwater table

class, other ones are maps of quantitative parameters such as Mean Highest Watertable and fortnightly expectations of water table depth throughout the year (constituting the regime graph for each grid cell).

This method is based on the use of measured water table depths at various places and time periods. These point data are then interpolated, using various sources of geographical information such as the soil map, digital elevation models and the location of drainage networks, etc. As the mapping method is geostatistical in nature, it quantifies the uncertainty of most of the mapped parameters. Thus maps of the uncertainty are produced as well, which allows for identifying areas where the maps can or should be improved.

The development of these methods ranging from low cost and quality to high cost and quality allows a method for revision to be selected which best suits both the purposes of revision and available funds. Moreover, Finke *et al.* (1994) also designed a statistical procedure to compare the differences between the present groundwater table depth and the depth classes shown on the existing soil map sheet. For this it uses actual data from time series on groundwater levels from the national monitoring network of the Netherlands Institute of Applied Geosciences TNO (NITG -TNO; see below).

Determination of areas in need of revision

The procedures developed allow objective answers to two important questions:

- Which areas are in need of a revision of groundwater depth classes?
- What is the order of importance (priority ranking) of these areas?

This analysis was restricted to the Pleistocene part of the Netherlands as most of the Holocene part, the 'polder district', has controlled groundwater levels. The results of this analysis was that about 290,000ha urgently needed revision of the groundwater table maps.

Execution of revision

At first, a provisional revision of 290,000ha was completed, using cost-effective methods (Finke *et al.*, 1994). After this, national and regional authorities ordered the production of very detailed (1:10,000) maps of the water table (Figure 1) in 1,790,000ha (i.e. 55% of the Netherlands). Hereby the remapping method using digital elevation models described above was applied (Finke *et al.*, 2004).

Probability sampling of mapping units

The method of probability sampling is described by De Gruijter and Ter Braak (1990) and Finke *et al.* (1996). The final goal of this sampling programme is to cover all soil features described by the legend of the 1:50,000 scale soil map (Van der Pouw 1991, 1996). Therefore the probability-sampling programme has to cover the three sections of the soil legend for:

- Describing and coding the soil units;
- Groundwater depth (GD) classes;
- Special soil features.

A mapping unit code combines the relevant codes from these three sections.

At the start of the probability-sampling programme, the focus was on sampling of the soil units. This turned out to be a large task and therefore a time-consuming, expensive operation.

Consequently the strategy was changed and the units of the groundwater depth classes, of which there are fewer, are being sampled. The probability sampling of this section is finished and provides our national soil information store with a unique database: statistically reliable information on a number of basic soil variables (e.g. pH, CEC, organic matter content, etc.) together with a set of about 1,450 geo-referenced profile descriptions. The sampling method also permits the construction of variograms for these variables.

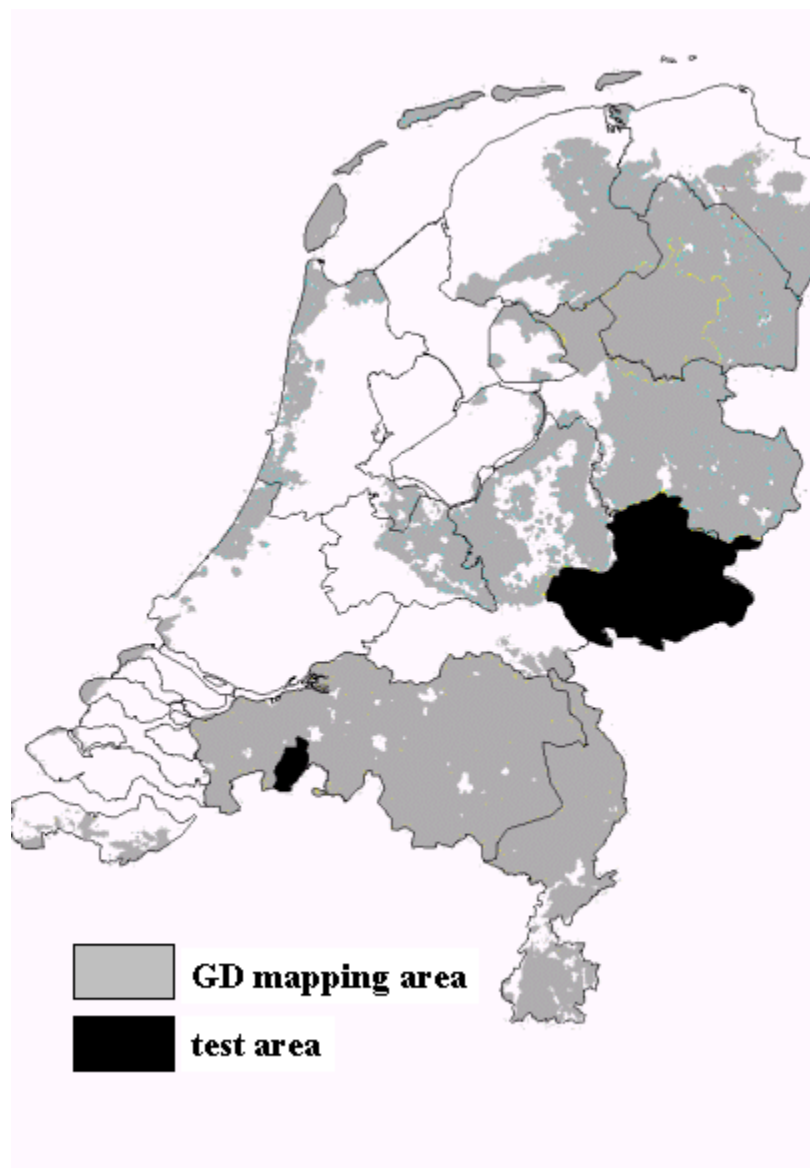


Figure 1: Extent of 1:10,000 watertable re-mapping projects

Collection of new data

The probability-sampling programme is also used for the third objective, that of the upgrading programme, i.e. the collection of new soil data. This involves, for instance, the determination of oxalate-extractable Fe and Al as well as phosphate on all samples. Together with the mean highest groundwater level these parameters determine the Phosphate Sorption Capacity and the degree of Phosphate Saturation at each sampled location.

These parameters are of eminent importance in the assessment of eutrophication hazards of surface waters that may be caused by manuring and increasing groundwater levels to abate human-induced drought. The samples are stored to allow for the future determination of other parameters such as heavy metals, following the same statistical sampling design.

So far, the resulting soil parameter database has been used for a statistically sound assessment of carbon stocks for the Kyoto reports, for the parametrisation of national-scale nutrient fate models and for the reliable estimation of acreages of phosphate-saturated agricultural soils.

Soil Information at Detailed Level

Detailed surveys have 'always' been an important activity of Dutch soil survey, and have been executed as commissioned projects from the beginning. Since the mid-1980s, maps and profile descriptions have been digitised. Digital detailed soil maps now cover about 250,000ha (Figure 2).

The growing competition for space and environmental quality of the rural areas also had consequences for the national 'Service for Land and Water Management' (DLG) which is in charge of the execution of rural development and reconstruction projects. Since the early 1990s DLG has been giving more emphasis to the interests of environmental quality and nature development. Similarly, DLG has recently started to evaluate the consequences of the Malta Agreement on the protection and survey of our archaeological heritage.

As DLG is also the major organisation for commissioning detailed soil surveys, these surveys naturally became more linked to the same subjects. This stimulated the development of a more ecologically based soil survey and land evaluation and the development of a survey integrating archaeology, soil inventory and landscape genesis, including historic land use. Recently DLG

commissioned the first projects in these two new fields.

National Soil Monitoring *sensu stricto*

This type of soil monitoring is only carried out by the National Institute of Public Health and Environmental Protection (RIVM). It conducts a national soil quality monitoring programme 'Soil monitoring and diagnosis' to generate information on the actual quality and its trend in the soils of The Netherlands.

The results are of great importance to the Institute's consultancy task with respect to environmental matters to the Dutch Government, i.e. the preparation and evaluation of policies on the abatement of pollution, eutrophication and acidification. Sampling is carried out once every five years (van Duijvenbooden, 1993) and focuses on rural areas.

In 1994, 20 intensively managed cattle farms (i.e. farms with a high phosphate production) and 20 forest sites (deciduous, pine and mixed vegetation) on sandy soils were sampled. Concentrations of heavy metals, polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides and triazines in the topsoil (0-10cm) and the litter layer of the forest sites have been reported (Groot *et al.*, 1998).

National Monitoring of Shallow Groundwater

When the subject of soil monitoring is broadened to include monitoring of the level and quality of the upper phreatic groundwater, then very much more monitoring is required. In view of the reciprocal influences of soil quality on the one hand and level and quality of the shallow groundwater on the other hand, it seems justified to cover also shallow groundwater under the umbrella of soil monitoring.

Groundwater level

The Netherlands Institute for Applied Geosciences (NITG-TNO) maintains a long-term national groundwater monitoring network, which presently comprises approximately 15,000 observation points.

All data are stored in a GIS which is accessible on-line and which is used for the planning and the evaluation of the aquatic infrastructure, to evaluate effects of groundwater extraction and water conservation policies and for a wide variety of scientific research on water quantity and quality.



Figure 2: Location of detailed soil surveys with digitised maps & databases

Groundwater quality

The National Institute of Public Health and Environmental Protection (RIVM) also conducts a National Groundwater Quality Monitoring Network (NGMN), comprising about 400 locations. It was established by 1984:

1. To determine the quality of the groundwater per land use and soil type and to construct maps;
2. To detect changes in the groundwater quality.

Groundwater is sampled annually and analysed for a number of anions and cations, amongst others, chloride, nitrate, ammonium, total phosphorus, dissolved organic carbon, pH, electrical conductivity (EC) and a number of inorganic micro-components (including Zn, Al, Cd).

Van Drecht *et al.* (1996) give a detailed account of Dutch groundwater quality based on monitoring results over the period 1984-1993, while Reijnders *et al.* (1998) over the same period concentrate on nitrate and aluminium because of their relevance to the environment and public health.

Some important conclusions include:

1. Average nitrate concentrations in shallow groundwater are under the target value for nitrate N (5.6g/m^3) in the west of the country and in the river areas constituted by clay and peat;
2. Average nitrate concentrations in the sandy areas in the east of the country are higher than in the west. Concentrations in the east in shallow groundwater under maize are significantly higher than the target value;
3. The highest concentrations of aluminium are also found in the sandy areas in the east. Under maize on sand the concentrations are significantly higher than the drinking water standard (200mg/m^3).

Long-term Monitoring Programme of Forest Health

Every 5 years, the health of a substantial number of forests in The Netherlands is assessed by evaluating soil quality (i.e. acidity, eutrophication status) and its effect on canopy growth, etc. These data are entered in the national soil database and are also incorporated in European Forest Soil Monitoring programmes.

Use of Soil Information

It can be stated with some certainty that there is hardly an environmental, nature conservation or rural planning project in The Netherlands beyond the point scale that does not use soil data in some way.

This is partly due to the value and quality of the data with respect to these uses, and partly to the fact that the data are easily available. Below, three typical examples of the use of soil data at the national scale are briefly described.

Definition and Implementation of N-restriction Policy

The Dutch Ministries of Agriculture, Nature and Fisheries, and of Housing, Spatial Planning and the Environment, have been using the digital Soil Map of The Netherlands, scale 1:50,000, to classify areas where surface application of organic manure is not allowed. Classification was based on the surface texture of all map units of the soil map.

The resulting maps became an appendix to the Law (Staatsblad 385, 1991, Bijlage I) and were used for field inspection. Recently a refined classification was made with the purpose of mapping dry sandy lots with agricultural use at a scale of 1:50,000. These lots may be subject to more strict N-restriction policy in the near future if current policies fail to satisfy environmental thresholds.

Aquatic Outlook Project

The Dutch Ministry of Public Works and Water Management commissioned a study on the effect of present and future nitrogen and phosphate emissions from agricultural areas to Dutch surface waters (Boers *et al.*, 1997). Soil and groundwater table maps, soil physical and soil chemical data as well as pedotransfer functions were used to parametrise and to validate N, P and H₂O fate models.

These models were:

1. DEMGEN to compute water balances.
2. ANIMO to compute the behaviour and transport of P and N in the soil based on animal manure, fertiliser applications and computed water balances. Among the processes considered, crop uptake, mineralisation and immobilisation, nitrification, denitrification, sorption on and desorption from the soil complex, surface and subsurface runoff and

leaching to surface water and groundwater are the most important.

The models were used to explore the effect of the Dutch manure policy up to 1993 and of five alternative future N, P and water policy options between 1985 and 2045 on (predominantly) surface water quality. Results, taken with permission from Boers *et al.*, 1997 (as in Figure 3), can be summarised as follows:

1. The present manure policy, POLICY95, resulted ultimately in a computed reduction of nitrogen runoff by 34%. This reduction was almost completely realised by 2015. The computed phosphate runoff stabilised during the period until 2045;
2. The considerably lower manuring in the ENVIRONMENT variant led to a realisation of the current emission reduction targets for nitrogen (50% reduction in 1995 and ultimately 70%, both compared to 1985). The current emission reduction targets for phosphate (50% reduction in 1995 and ultimately 75%, both compared to 1985) were not met by the ENVIRONMENT variant. The reason for this is the historical loading of the soil, which determines the runoff. Even in the ENVIRONMENT variant, phosphate loading of the soil still increased, albeit at a slower pace;
3. Continuation of the manure application of 1993 resulted in a continued computed increase of phosphate and, to a lesser extent, nitrogen runoff.

Environmental Outlook Project

The Dutch Ministry of Housing, Spatial Planning and the Environment regularly commissions studies in which attention is to be paid to the effects of proposed and intended policy efforts on CO₂, NO_x, NH₃, phosphate and nitrogen emission levels and on subsequent levels in the air, soil and groundwater.

This work is carried out every four years by the National Institute for Public Health and the Environment (RIVM), and evaluates both national policies and the Dutch status in the context of European Legislation.

The soil data used are comparable to those of the Aquatic Outlook Project and are included in a wide variety of models. For an extensive description of this project and its results reference is made to Albers (1997).

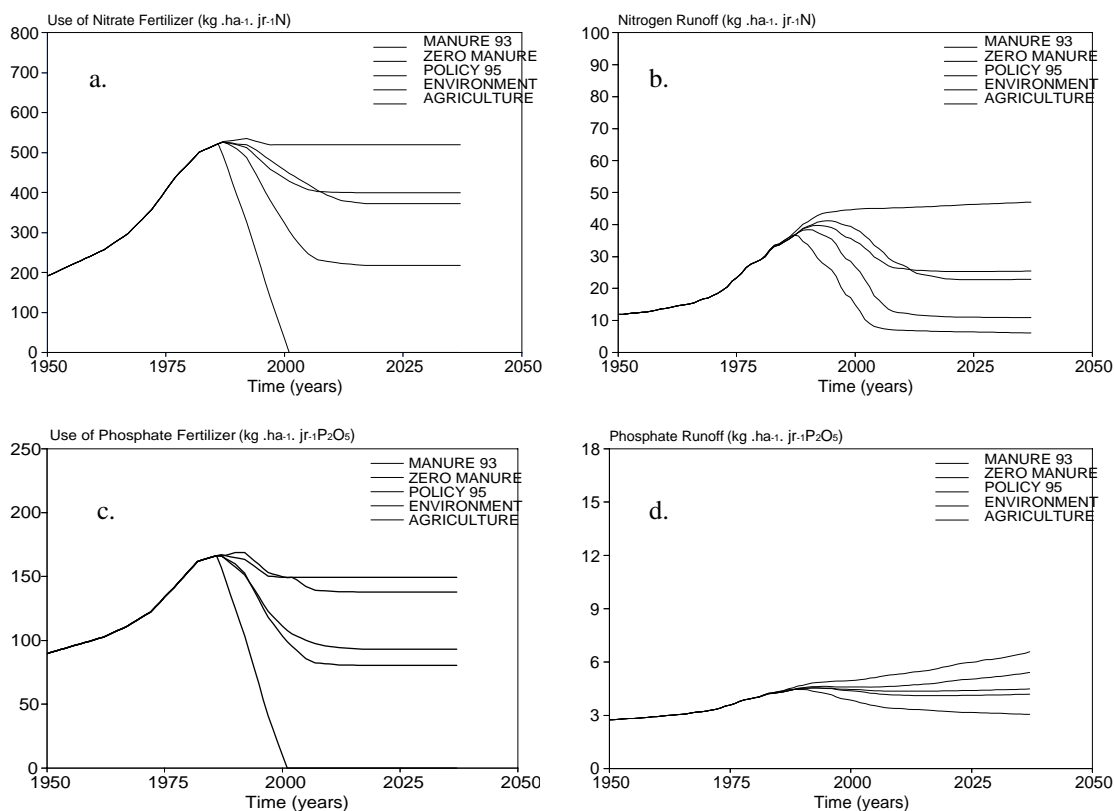


Figure 3: Average use of N (a) and P (b) fertiliser in Dutch agriculture and average runoff of N (c) and P (d) to Dutch surface waters from arable land.

[Reproduced with permission from Boers *et al.*, 1997.]

Future

The application range for soil data collection is widening. A brief overview of changing activities with respect to data collection, the use of new and existing data and of the consequences of developments in information technology is given below.

Data Collection

Soil inventories become ever more tailored to the wishes/questions of regional stakeholders. New developments are:

- ecological soil mapping (soil mapping in conjunction with vegetation mapping and the description of humus profiles);
- ecohydrological system analysis (soil mapping as part of the definition and interpretation of hydrological systems and their analysis for nature development possibilities);
- archaeological soil surveys (aiming at the identification of archeological sites and reconstruction of prehistorical landscapes);

landscape reconstruction surveys (soil mapping as a tool in reconstructing the geomorphological and cultural history of a landscape).

Development of New Relevant Databases and Data use

Very recently a national database with digital elevation data has become available. The density of information is about 16 sites per ha, which allows for detailed spatial analyses prior to a detailed soil survey. The availability of detailed digital elevation models improves the quality and cost efficiency of soil surveys and is already being applied routinely in the mapping of groundwater depth dynamics, and geomorphological surveys.

Soil databases become less an end-product and more an intermediate product in conjunction with their application in rural planning projects. This involves operational methods to upscale information and to estimate process parameters for simulation models.

Information Technology and Data Availability

The role of Information Technology during soil surveys is increasing:

- Global Position Systems, field-digitisation and attribute coding of soil maps help to reduce cost and to increase quality of the production process;
- The quality of soil data and its documentation in meta-information databases via the internet becomes ever more important;
- The accessibility of digitised soil maps and databases to the public with Internet technology was recently implemented. For the future it is foreseen that soil data users will be able not only to access but also make on-line interpretations of soil data via the internet.

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