Unravelling changes in soil fertility of agricultural land in The Netherlands

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Abstract

On fertile soils, high-yielding crop production systems can be built which are indispensable both for profitable farming and for feeding the steadily increasing world population. With its high soil fertility, agriculture in the Netherlands is one of the most productive in the world. The high soil fertility is partly inherited from sea and rivers, partly it is men-made through manure and fertilizer applications. However, from the 1980s manure and fertilizer applications are limited through governmental regulations.

This thesis aims to increase the understanding of spatial variations and changes over time in soil fertility of farmers' fields in the Netherlands during the last century. More specifically, it addresses the following research questions: i) which changes have taken place in soil organic matter (SOM) and soil phosphorus (P) contents in the period 1970 to 2000s, ii) will mean soil P status develop towards the optimal agricultural range, with a small standard deviation when virgin soil is cultivated with high craftsmanship?, iii) how did herbage quality respond to changes in mean soil fertility in dairy farming, iv) what are farmers' perceptions and concerns regarding soil fertility?, and v) how to improve the usability of fertilization recommendations, using new knowledge? A large data base of a laboratory for routine soil, manure, herbage tests (BLGG) was analysed statistically, and a questionnaire was conducted.

Results show that the mean SOM content of mineral soils remained stable during the last decades, despite worldwide reports about declining SOM contents, and concerns expressed by farmers. Restrictions on the use of animal manure did not yet have an effect on dairy farms; soil P status of grassland and mineral content of herbage remained within the optimal range during the last few decades, but crude protein decreased. Soil P status on arable land increased until the 2000s, partly to above agronomical optimal ranges. Risk avoidance seems a decisive factor for pursuing these higher statuses, stressing the need for improved recommendations. Since implementing new insights proves hard, a three-step schedule for incorporating results of novel soil tests into fertilization recommendations is suggested. Farmers endorse the importance of soil fertility and SOM, and P status should be monitored, including anticipated information about soil structure and soil life.

Keywords:

Soil fertility, soil test, phosphorus, soil organic matter, soil organic carbon, fertilization recommendation, data base, the Netherlands.

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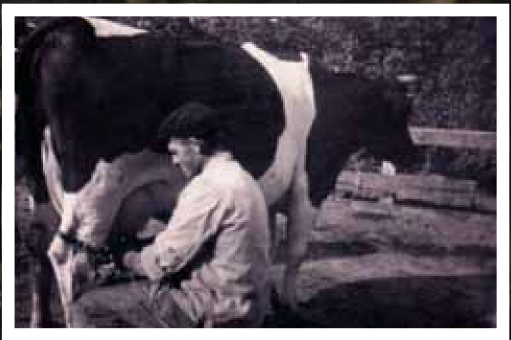


Chapter 1

GENERAL INTRODUCTION

Background

An important and intriguing question is how to feed an expected population of some 9 billion by the middle of the 21st century (e.g. Smil, 2000; Godfray et al., 2010; Pretty et al., 2010); an increase of 2 to 3 billion people in 4 decades (Figure 1a). Moreover, people will likely eat more animal-derived food; the consumption of meat per capita has greatly increased during the last decades (Figure 1b). More meat consumption implies that additional crop production is needed to feed livestock (Stokstad, 2010). Thus for 2050, it has been projected that total crop production needs to have increased by 70% (FAO, 2012).

As there is no global surplus of food, and suitable land reserves are limited, mean food production per unit of surface area must grow substantially (FAO, 2012; Khan & Hanjra, 2009). Higher production levels can be realised by plant breeding, improved techniques (e.g. with respect to irrigation, crop fertilization, crop protection), and widespread introduction of good agricultural practice through educational activities, including proper soil management. The condition of the soil is the basis of agricultural production, usually referred to as the soil fertility. A common definition of soil fertility is 'the crop production capacity of the soil', though some scholars prefer a more specific definition, such as 'the nutrient supplying and retaining capacity of the soil' (Reuler & Prins, 1993; Patzel et al., 2000; Janssen & De Willigen, 2006). On soils with high natural or improved soil fertility, high-yielding production systems can be built (Van Ittersum & Rabbinge, 1997).

This thesis deals with soil fertility in the Netherlands. Agriculture in the Netherlands is one of the most productive in the world, due to in part its soil fertility. Part of this soil fertility was inherited from the sea and the river delta made up by the Rhine, Meuse and Scheldt. The other part is man-made, because the soils in the eastern and southern parts of the country originally were poor sandy soils (Slicher Van Bath, 1956). The study of soil fertility in the Netherlands is of interest because of its geographic situation, its intensive agriculture and more recently its governmental regulations limiting manure and fertilizer applications. Before focussing on soil fertility in the Netherlands, I first give a brief overview of the role of soil fertility in the development of global agriculture, and of agricultural development and soil fertility research in the Netherlands.

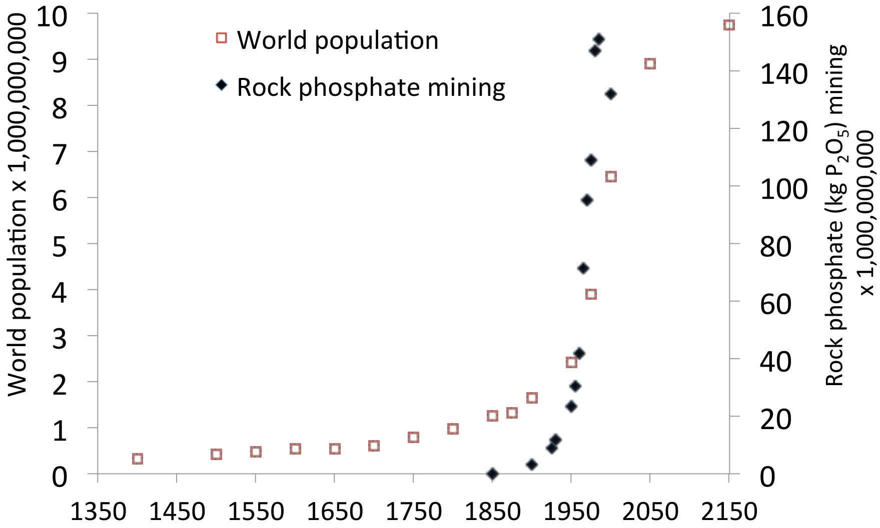


Figure 1a *Changes in the number of people in the world from the late middle ages till 2010, plus predictions for the years 2050 and 2150 (FAO, 2012). Also shown are the amounts of rock phosphate mined in the world from 1850 till 2000 (USGS data compiled by Buckingham & Jasinski, 2006).*

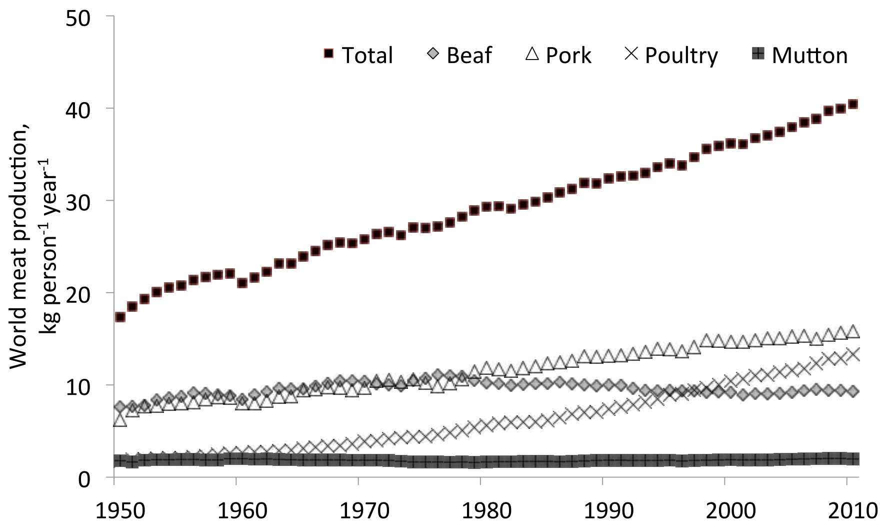


Figure 1b *Changes in world meat production, expressed in kg per person per year (FAO, 2012; World Resources Institute, 2012).*

A. Role of soil fertility in agricultural development

Ancient history (domestication)

Early domestication of plants and animals originated in the Near East around 11000 BC. Cultivated cereals produced greater yields than unattended wild cereals (Araus et al., 2001). Ancient people likely used a trial and error approach in determining where to farm. Agricultural settlements were established in places where the soils were fertile; the area between the Tigris and Euphrates rivers in Iraq was civilized by Mesopotamians who adjusted their cropping patterns based on observed spatial variation in soil fertility (Krupenikov, 1992). The land was also irrigated on some places (southern Iraq; 9500 BC), but this led ultimately to the downfall of these settlements, due to soil salinization (Brevik, 2005).

Other early civilizations also arose near rivers, for example the Yangshao culture around the Yellow river in China (5000 – 3000 BC) and the Indus valley civilization around the river Indus in India (3300 – 1300 BC). The Egyptians (3300 - 330 BC) understood that the Nile floods watered and fertilized the soils, and that floods removed accumulations of undesired salts (Hillel, 1991). Around 1400 BC Moses sent men to Canaan to explore the region. He tasked them among others “How is the soil? Is it fertile or poor?” (Numbers 13: 18 – 20: New International Version).

The invention of the plough (driven by animals) was of major importance, for it allowed agriculture in areas relatively low in soil fertility (areas not flooded by rivers and therefore not regularly fertilized with clay and silt); ploughing among others mobilizes plant nutrients in soil.

Agriculture reached Europe in two ways, one from the Near East to the coasts of Italy and France (Binder, 2000) and another from the Near East via Greece to Hungary. Around 5500 BC, Central and Western Europe switched to domestication. Emmer wheat, einkorn wheat, barley, peas, flax were cultivated. There was cattle (Bogucki, 1995), but also sheep and goats were kept. By 5000 BC, farming was common in some areas of Western Europe.

Classical antiquity (ancient Greek and Roman Emipire)

In ancient Greece it was recognized that soil nourishes the plant. Also understanding of certain soil properties increased (e.g. soil texture); ploughs for different soils were developed, and crops suitable for a specific soil were selected (Krupenikov, 1992). The population in the Greek Empire increased significantly in response to the prosperity brought by food production and trading. However, despite their knowledge of soil, they apparently did not develop effective techniques to combat erosion. Because of erosion, large amounts of nutrients and organic matter were lost and consequently soil fertility declined. Plato, in his Crititas, observed:

"What now remains compared with what then existed is like the skeleton of a sick man, all the fat and soft earth having wasted away, and only the bare framework of the land being left."

Soil knowledge by the Romans elaborated on Greek knowledge. Arable farming and domestication of animals were well established in Western Europe during Roman times, but yields per unit of surface area were low, so that nearly half the crop had to be used as seed. At the beginning of the Roman era, Cato promoted the use of manure and green manure crops to improve soil fertility (Krupenikov, 1992). Especially the use of green manure crops seems to have been a crucial step forward compared with Greek agriculture.

Middle Ages (500 – 1500)

Agriculture in Europe declined after the fall of the Roman Empire (5^{th} century AD). The majority of people lived in small villages with only a few hectares of fields, cultivated in so-called two-field systems. This system implied that one field was cultivated and the other was left fallow to prevent to some extent soil fertility decline. Villages were isolated and there was a constant danger of raids. Because of this, trade, commerce, and exchange of agricultural knowledge were reduced to only a fraction of what had been common during most of the Roman days.

Improvements took place again from the 11^{th} century. Raids became lesser; stability increased. A new plough, more suitable for wet, heavier textured soils of Northern Europe was introduced, which turned the upper layer and increased yields considerably (Tauger, 2011). This plough was increasingly pulled by horses instead of oxen. The two-field rotation was gradually replaced by a three-fold system. The three-fold system still included a season of fallow, but incorporated also several summer crops beside the winter crops that had been custom in the two-field system, notably legumes. Further, soils were fertilized with manure, and sometimes also with marlstone. All this increased production and made food supply more varied.

Early and classical modernity (1500 – 1900)

After Columbus' discovery of America in 1492, the intercontinental exchange of crops and livestock started. Tomato, maize, potato, manioc, cocoa, bean, and tobacco were introduced into the Old World while varieties of wheat, spices, coffee, and sugar cane arrived in the New World. Maize was introduced in the 16^{th} century and became increasingly important as staple food crop (Tenaillon & Charcosset, 2011). Potatoes became an important crop in northern Europe, first mainly for animal feed, later (>1700) for human consumption.

Nutrient cycling in soils was studied by Leonardo da Vinci (1452 – 1519) using pots containing of grass (Krupenikov, 1992). Bernard Palissy (1510 – 1589) concluded that the benefits of ash or manure for plant nutrition originated from salts (Brevik & Hartemink, 2010).

By early 19th century, agricultural techniques, seed stocks and cultivars had improved and yield per hectare was much higher than in the Middle Ages. Combined with increased health care, population increased strongly, which worried Maltus (1766 – 1834), who stated that food production could increase only linearly while human population would increase exponentially. At the same time important new insights were documented. The "humus theory of plant nutrition" was promoted by Albrecht Thaer (1752 – 1828). One of his students (C. Sprengel, 1787 – 1859) proposed a theory on mineral nutrition of plants and introduced the law of the minimum at least 12 years before Justus von Liebig' more famous work (Feller et al., 2003). Von Liebig (1803 – 1873) published "Chemistry as Supplement to Farming and Plant Physiology" (Von Liebig, 1840) and explained the 'Law of the Minimum, that states that yield is proportional to the amount of the most limiting nutrient'. This insight contributed to the application of mineral fertilizers and a founded insight in the possibilities to maintain or restore soil fertility. Around 1850, superphosphates were produced in Great Britain, and the first potash (K_2O) mines opened in Germany.

Late modernity

In the 20th century, agricultural techniques developed and were implemented much more rapidly than previously. In 1909, Haber managed to solidify nitrogen in a useful and stable form (Leigh, 2004), which marked the beginning of artificial N-fertilizers. Improved possibilities for transport led to more widespread use of mineral fertilizers. For example, phosphate rock usage increased enormously (Figure 1a). These mineral inputs greatly increased yields and soil fertility. In most European, American and Asian countries soil fertility increased during the last century.

In the second half of the 20th century concerns increased about the impacts of inputs into farming systems (crop protection, mineral fertilizers and manure) on, e.g., water quality and ecosystems (e.g. Van Breemen et al., 1984; Stoate et al., 2001). Although some of the surplus N may accumulate in soil organic matter, large amounts leach to groundwater and surface waters. Enrichment of soils with P increases the risk of P losses to the aquatic environment through erosion, overland flow, and subsurface leaching (Pautler & Sims, 2000; Schoumans & Chardon, 2003). Also reports about (toxic) levels of copper (Cu) and Zinc (Zn) appeared (Lexmond & De Haan, 1977; Moolenaar, 1998). In addition, there are concerns about depleting P rock resources (Heffer et al., 2006; Cordell et al., 2009, Smit et al., 2009).

B. Agriculture in the Netherlands

From first agricultural settlements – 20th century

The Netherlands is situated in western Europe along the North Sea (Figure 2). The north-western half of the country is below sea level and has marine clay soils and peat soils with many polders, drainage ditches and canals. The other half has predominantly sandy soils (fluvio, glacial and eolian deposits). Climate is temperate (mean temperature 11°C), with rainfall equally distributed over the year (total rainfall ~800 mm per year).

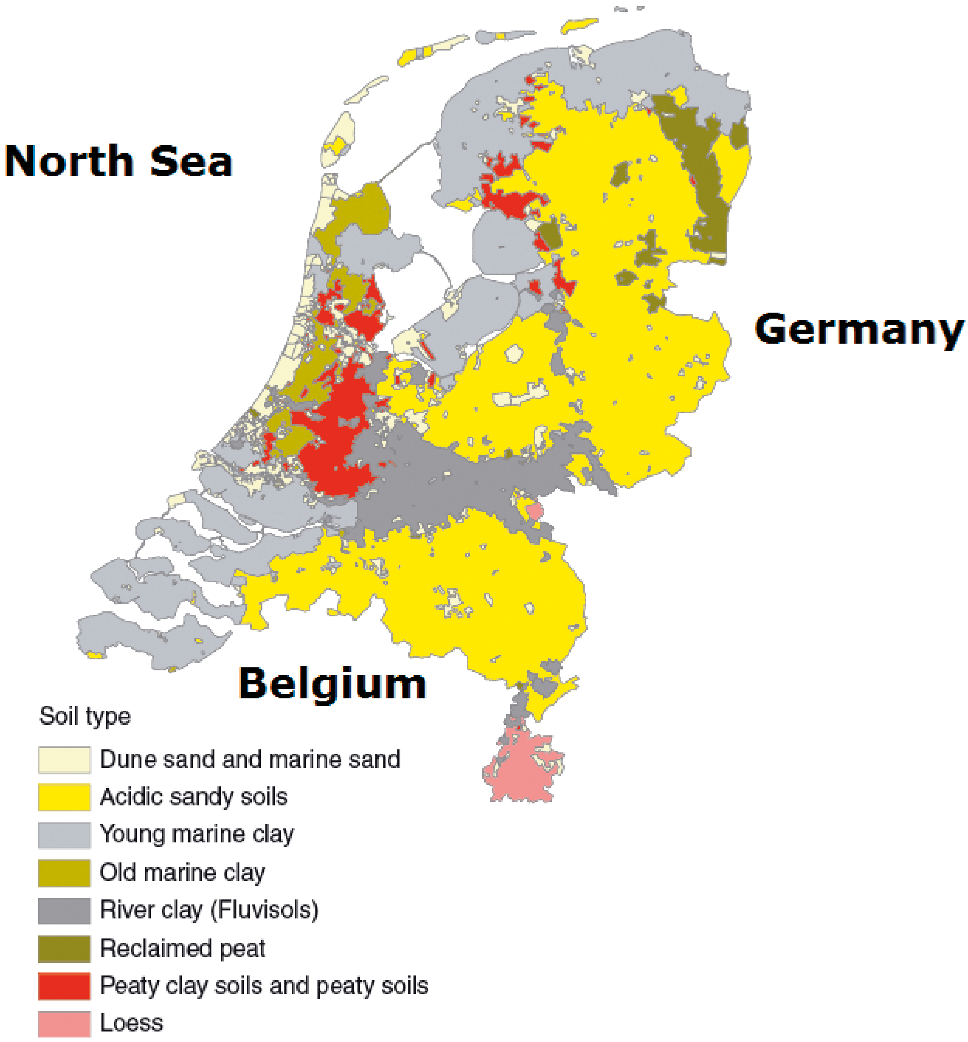


Figure 2 The Netherlands, with spatial distribution of main soil types.

Evidence of early settlements (~5000 BC) has been found on elevated areas in the southern part of the country. Expansion to other regions was slow, probably because of the risk of temporarily flooding. Early settlements in the north and west were on artificial dwelling hills (so-called 'terps').

From the 10th century onwards, large parts of the coastal provinces (Zealand, Holland) were reclaimed from the sea and lakes by making polders, including the Green Heart (between the cities Amsterdam, Utrecht and The Hague/Rotterdam). Dikes and floodgates were created and accompanied by water authorities (Slicher Van Bath, 1960; Bieleman, 2010). Increased drainage also contributed to subsidence of peat and clay soils, which made cultivation increasingly harder. This problem in turn stimulated grain trade (15th century) and subsequently the trade of other commodities, which turned out to be highly beneficial for the economy and indirectly contributed to the so-called Golden Age. The newly earned funds were invested in further reclamations (Hoeksema, 2007). In the middle ages, wheat production was 1500 kg per hectare on the calcareous clayey soils in Zealand, twice the yield from the loess and sandy areas around Maastricht (province Limburg).

Peat soils were increasingly exploited for use as fuel from the 17th century. This resulted in many shallow lakes in the western half of the country, which in part were drained, and the resulting polders with marine clay soils were used for agricultural land. Bogs in the north-eastern half were drained via canals and the underlying glacial sandy deposits were amended and also used for agriculture.

From 20th century

Around the end of the 19th century farming cooperatives were initiated by farmers for milk processing, but also to purchase mineral fertilizers. Affordable mineral fertilizers (potash fertilizers, superphosphate, lime) made nutrient input not merely dependent on application of animal manure, sewage sludge, ashes or sods. It made fallow no longer necessary and it allowed farmers to specialize in either crop production or animal production, especially after large-scale introduction of artificial N fertilizer from the 1950s onward. Changes in fertilizers and land use are shown in Figures 3 and 4 respectively.

From the 1950s, agriculture was increasingly influenced by the Common Agricultural Policy (CAP) of the European Union (formerly European Economic Community). The CAP focused on increasing agricultural production and encouraging agricultural intensification (Figure 5). Imports of cheap animal feed ingredients facilitated the intensification and specialisation of livestock production, and resulted in manure production rates exceeding

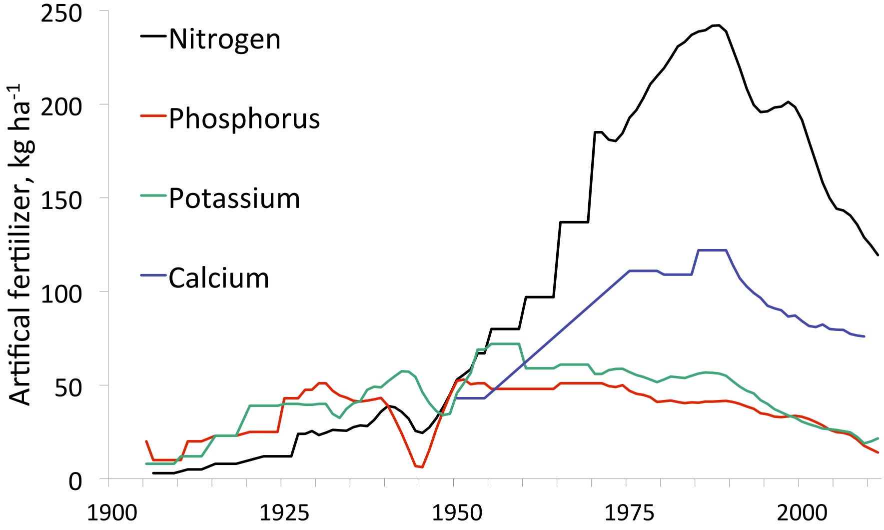


Figure 3 *Usage of artificial fertilizer (N, P_2O_5, K_2O, CaO, in kg per ha per year) in the Netherlands from 1905 – 2011 (Otten & Veenstra, 1951; Dechering, 1956; Cnossen & Duursma, 1939; CBS 2012).*

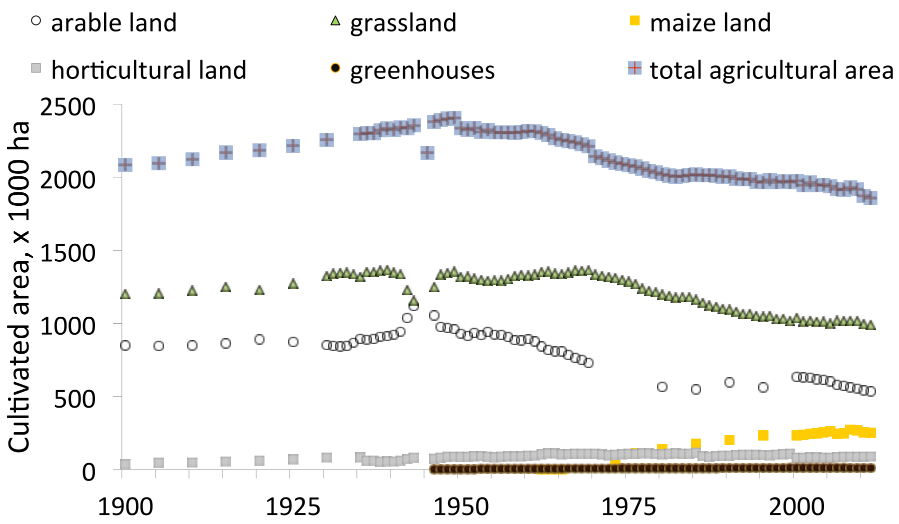


Figure 4 *Changes in cultivated area of main crops in the Netherlands from 1900 – 2011(CBS, 2012).*

crop requirements on many livestock farms, especially on sandy soils in the southern and eastern part of the country (Van der Molen et al., 1998). Since then, these sandy soils have received the highest manure P loadings within Europe, resulting in a large build-up of soil P regionally.

Between 1950 and 1980 the number of dairy cattle increased by a factor of 1.5 and milk production per cow by a factor of only 1.2 (Figure 5). After the introduction of milk quota in 1984, number of dairy cattle decreased, while the milk production per cow increased strongly. The total national input in dairy farming increased from 8 to 153 million kg N year^{-1} via concentrates, and from 70 to 379 million kg N year^{-1} with mineral fertilizers, but the output in milk and meat increased only from 36 to 83 million kg N year^{-1} (Ketelaars & Van der Ven, 1992). Thus, the N surplus (import of concentrates, and fertilizers minus production with milk and meat) increased from 40 to 450 million kg N year^{-1}.

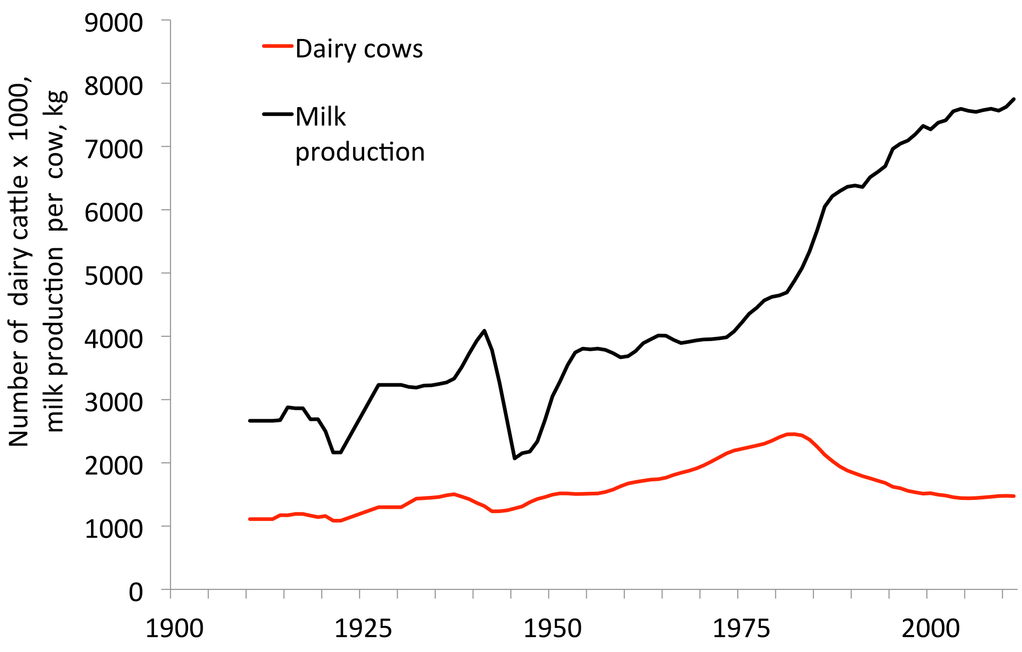


Figure 5 Changes in number of dairy cows and in milk production per dairy cow in the Netherlands during the period 1910 to 2011 (data CBS, 2012, modified).

The national N surplus for the whole agricultural sector increased to more than 700 million kg year^{-1} in the mid-1980s, with dairy farming as the primary source (Van Keulen et al., 1996). In the period 1950 – 2000 on average 4000 kg P_2O_5 ha^{-1} was accumulated (Smaling et al, 1999; Boers & Noij, 1997). However, surpluses decreased strongly from the mid-1980s onwards due to governmental regulations (Figure 6). In 1990 the surplus was >50 kg P_2O_5 ha^{-1} for both arable farms and dairy farms. Twenty years later, this surplus had decreased to < 20 kg P_2O_5 ha^{-1}.

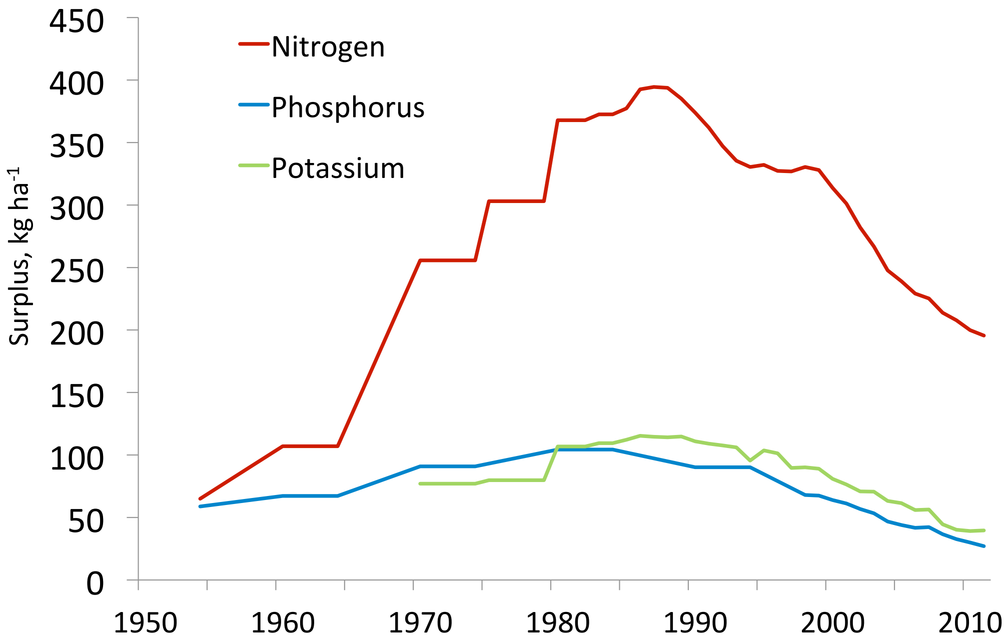


Figure 6 *Changes in the mean surpluses (total input minus output in harvest crop product) of nitrogen (N), phosphorus (P_2O_5) and potassium (K2O) of agricultural land during the period 1950 to 2011 (Smaling* et al., *1999; CBS, 2012, LEI, 2012).*

Although the expansion of agricultural production has slowed down from the mid-1980s, The Netherlands is still a major producer and international trader of flowers, meat, meat product, fruit, vegetables, beer, dairy product, starch derivatives and seed. It ranks together with France on the second place on the list of exporters of agricultural products, behind the United States. Its production per hectare and per cow are among the highest in the world (Figure 7).

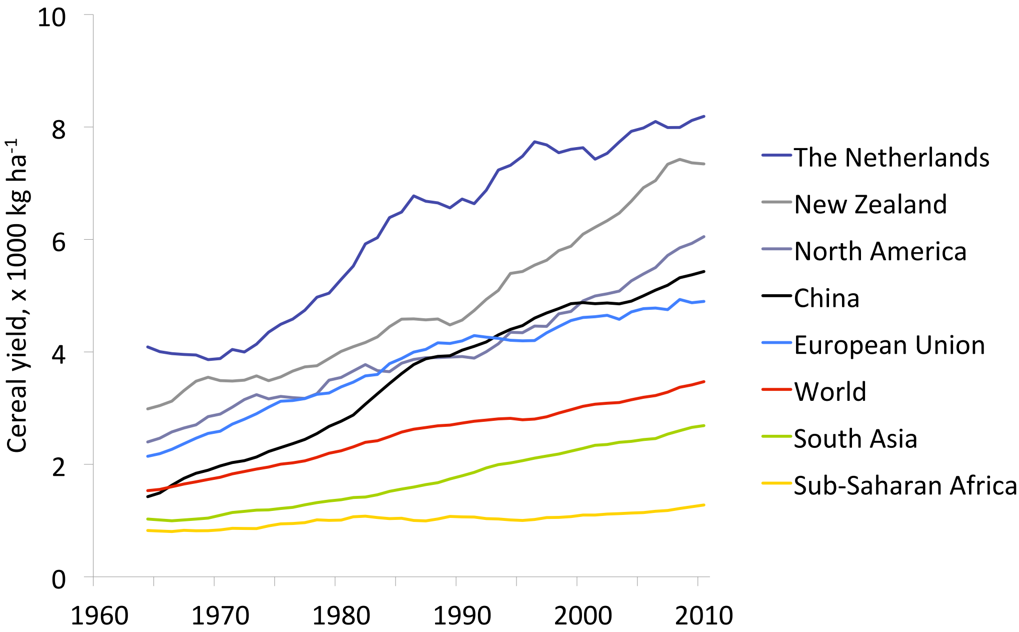


Figure 7 *Changes in mean yield of cereals(wheat, rice, maize, barley, oats, rye, millet, sorghum, and mixed grains) in selected countries of the world during five decades. Production data on cereals relate to crops harvested for dry grain only. Cereal crops harvested for hay or harvested green for food, feed, or silage and those used for grazing are excluded (FAO, 2012, Worldbank.org, 2012).*

The intensification of agricultural production sketched above resulted in increasing environmental costs, recognised by some scientists from the early 1970s onwards. The policy response came in 1984, when the government introduced a policy with increasing restrictions and gradual tightening of manure and fertilizer application limits. The first phase (1984 – 1990) included milk and manure quotas per farm and P-based limits of manure application to land (Oenema, 2004). In the second phase (1991 – 1997), policies focused on decreasing manure production and tightening application limits, low-ammonia emission manure storage and application methods, and a ban on manure and fertilizer applications in autumn and winter. The latter measure was also a response to the 1991 EU Nitrate Directive, with the main objective to reduce water pollution caused by nitrates from agriculture (Henkens & Van Keulen, 2001). The third phase started with the introduction of the Mineral Accounting System (MINAS) in 1998. Surpluses of N and P decreased strongly, but the European Court rejected MINAS as instrument to comply with the Nitrates Directive. In response, a system based on N and P application standards, differentiated by soil and crop type was introduced in 2006.

Overall, governmental policies have resulted in strongly decreased N and P surpluses, ammonia emissions, and nitrate leaching to groundwater and surface waters. However, targets for surface water quality, groundwater quality, and nature (biodiversity) protection have not been achieved in all regions yet. As a consequence, discussions about tightening the nutrient management policy are still on-going, which provokes protest by farmers about deceasing soil fertility and crop yields.

C. Soil fertility research

Traditional questions in soil fertility research are (Van Noordwijk, 1999):

1) To which extent are nutrients limiting crop yield on a given field?
2) How to measure soil fertility?
3) How effective are recently added nutrients relative to soil fertility, depending on type of fertilizer type, timing and placement?
4) At which input level are additional (marginal) benefits equal to additional costs?
5) What are the environmental effects of soil fertility and fertilizer application?

The fifth question is of more recent date (Van Noordwijk, 1999). Later, additional questions popped up, related to biodiversity, erosion control, and soil carbon sequestration. For answering question 1, it is necessary to know the potential production and nutrient requirements of a certain crop on the one hand and the total nutrient supply on the other hand. Questions 2 and 3 deal with natural soil fertility and the actual application of fertilizers, respectively. Question 4 focuses on the economy of fertilization and question 5 on the environment impacts.

Soil fertility is a function of the parent material of the soil, climatic conditions, soil forming processes, and agricultural and fertilization practices. There are three main components of soil fertility: physical, chemical, and biological (Abbott & Murphy, 2003). The level of soil fertility also depends on the interactions that occur between these three components. The physical components of soil fertility relates soil texture, soil structure, and water holding capacity. Chemical soil fertility relates to acidity, salinity, nutrient holding capacity and nutrient status. Biological soil fertility relates to the tremendous variety of organisms, mostly being positive or neutral for crop production, and a minority (though of great importance) are plant pathogenic. Among these three main components of soil fertility, chemical soil fertility can be managed most easily by farmers.

Soil organic matter

Soil organic matter (SOM) is generally considered as the pivotal element of soil fertility (Allison, 1973; Bauer and Black, 1994; Davidson, 2000). Consequently, the current state and its functions, have been investigated extensively. The primary source of SOM consists of plant residues, including root exudates. SOM is biologically decomposed at variable rates (Duchaufour, 1977). Besides the term SOM, also soil organic carbon (SOC) is used frequently, which refers to the C-component of SOM.

On a global scale, an estimated 1500 Pg (1 Pg = 10^{15} g) organic C is stored in the upper meter of the soil (Batjes, 1996; Janzen, 2004). This is about three times the amount of C in the aboveground biomass, and twice the amount of C present in the atmosphere as CO_2 (Schlesinger, 1997). Decomposition of SOM is stimulated by soil tillage and increases further due to global warming, thus enhancing the greenhouse gas effect (Lal et al., 1998; Lal, 2001; Janzen, 2004; Freibauer et al., 2004).

SOM content is important for soil functioning. Part of its benefits for soil fertility arise from its decomposition (Janzen, 2004, 2006), during which N, and to a lesser extent P, sulphur (S) and other nutrients, are released. SOM also contributes to the cation exchange capacity (CEC) of a soil (e.g. Leinweber et al., 1993; Tang et al., 2009). Soils with high amounts of SOM are able to retain large amounts of cations like calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na). SOM also influences water holding capacity (Lavelle & Spain, 2002) and soil structure. On heavy textured soils (clays), workability improves with increasing SOM levels. On the other hand, too high SOM contents may limit workability, e.g. silage maize is difficult to cultivate on peaty soils, because the tractor carrying capacity of the peat soil is relatively low. Soils very low in decomposable SOM are less disease suppressive against soil-borne plant pathogens (Bonanomi et al., 2010). Worldwide, there are increasing concerns about SOM depletion due to land use changes, intensification of soil cultivation, whole-crop harvesting for bio-energy purposes, as well as in cropping systems (less cereals, more root crops), and global warming (e.g. Sleutel et al., 2003; Hartemink, 2003; Bellamy et al., 2005). Depletion of SOM may affect soil fertility and hence crop productivity. However, the extent of SOM depletion has not been quantified well yet.

Soil phosphorus

Soil phosphorus is a main soil fertility characteristic, next to SOM and pH. In plants, P is essential for several physiological functions that involve energy transformations. It is a component of many cell constituents, including DNA, and plays a major role in several key processes, including photosynthesis and cell division (Westheimer, 1987). Adequate P is needed for the promotion of early root formation and growth, but it is also necessary for seed formation. Worldwide, P is a main crop-yield limiting nutrient, next to nitrogen, especially in highly weathered tropical soils in Africa and Latin America, and in unfertilized sandy soils.

Most of the P added to the soil as fertilizer and manure is rapidly bound by soil minerals in chemical forms that do not allow rapid release, causing low P concentrations in the soil solution. Still, these inputs contribute to the buffering capacity of soils by increasing the quantity of soil P. Worldwide, there are concerns about excessive accumulation of P in soils, which increases P leaching losses to surface water, leading to eutrophication and subsequent biodiversity loss of these waters. Excessive accumulation may occur in areas with intensive livestock production; here the import of P via animal feed and fertilizers is often much larger than the export of P via animal products and crop products.

On the other hand, arable farmers have concerns about decreasing soil P status due to high prices of P fertilizers, the fixation of added P to soil particles, rendering it unavailable to plants (e.g. Wang et al., 2012). Farmers in European Union also fear governmental regulations that limit the application of P to land. However, currently little is known about the regional distribution of plant-available P in soils.

D. Soil tests and fertilization recommendations

For obtaining insight in crop nutrient requirements and optimal soil fertility status, experimental fields have been designed. One of the first fertilization experiment was performed by Boussingault in 1837, who studied the benefits of crops grown in rotation. Other early experimental fields were those of Rothamsted (grass experiments since 1856), the Jordan Plots (plots with several crops and combinations of fertilizers and lime, started in 1869), and the Morrow plots (maize fields, started in 1876).

At about the same time soil testing started (which is defined here as a method to estimate soil fertility status). At first 'total' amounts of N, S, P, K, Ca, Mg, and also Fe were measured, assuming that these amounts would predict nutrient release during the growing season. This turned out to be no successful method, because there was hardly any relationship between 'total' nutrients in soil and crop yield. Thereafter elements extractable in strong acids were used, but also this method gave unsatisfactory correlations with crop yield (Domingo, 1955). An important discovery was that nutrients were present in the soil in several chemical forms, which vary in availability for uptake by plant roots. This resulted in soil tests using weak acids as extractants. Daubeny (1845) was the first to experiment with this by discriminating between 'active' and 'dormant' fractions of nutrients. Dyer (1894) was the first to use the term (plant) availability of nutrients explicitly. Since then, the search for suitable extractants and procedures for relating soil fertility to the response of crops to soil fertility and added manures and fertilizers has continued. This has resulted in a wealth of procedures, including differences in sampling procedures, which are different for different countries and regions, and for which there is often no clear mechanistic underpinning (e.g., Alva, 1993; Tunney et al., 1997). An overview of the variation in fertilizer-P recommendations in Europe based on soil testing was recently provided by Jordan-Meille et al. (2012).

Soil testing in the Netherlands

Based on growing interest in soil fertility and fertilization, five agricultural experimental stations were established in the Netherlands in the period 1877 – 1927. In their early years quality control of agricultural products was the main focal point. During the period 1890 – 1916 soil fertility research developed at the State Experimental Station in Groningen (Harmsen, 1991). The interest in soil-dependent crop productivity increased and the demands by farmers for soil tests increased correspondingly. In 1927, the laboratory for routine soil tests was split off from State Experimental Station, and continued independently as *Bedrijfslaboratorium* (Hoogterp, 1929; De Vries & Dechering, 1947).

From 1927 – 1930, only pH was analysed. From 1930, P-number (extraction with water at 50°C) and K-number were added. In 1933, P-citric number (i.e., extraction with 1% citric acid) was added. By 1947, pH, SOM, $CaCO_3$, P-number and P-citric, K, clay and sand content (texture analysis) had become routine (note that there were two soil tests for P). (Micro)nutrients Na, Cu, and Co were analysed incidentally on request. In the 1990s, N-total of grassland was included (Hassink, 1996; Vellinga, 1998).

All these soil characteristics were analysed according separate protocols, which was time consuming and, therefore, expensive. A multi-nutrient concept using 0.01 M $CaCl_2$ as extractant was proposed by Houba et al., (1990; 1994), and later more firmly by Van Erp (2002). From 2004 onwards, this concept was gradually introduced (e.g. Van Rotterdam – Los et al., 2012; Ros et al., 2009). Further, Near Infra-Red (NIR) technology was gradually introduced for analysis of among others SOM, N-total, and $CaCO_3$ (e.g. Malley et al., 1999; Vedder et al., 2009).

The research on soil fertility factors laid the foundation for the system of fertilizer recommendations on the basis of soil test results (Harmsen, 1991). Fertilization recommendations were given with the results of the soil test from 1927 onward, and were promoted also by agricultural extension services and agricultural education (Duijvendak et al., 2008). Recommendations were based on results of numerous experiments and expert judgement put together by committees of experts and advisors. Committees for bulb flowers, tree nurseries, fruit production, horticulture, arable farming, grassland and fodder crops, and for greenhouses were established and – at least for the main crops – are still existing and active (Anonymous 2012a, b). The peak in practical soil fertility and fertilization research was in the period 1950 – 1970, perhaps best indicated by the publication period of the Dutch journal “Buffer”, which dealt with practical questions of specialists regarding soil fertility and fertilization. It dealt with among others macronutrients, micronutrients, recommendations for a variety of crops, mineral and contents of manure (Anonymous, 1989). Knowledge of specialists was conveyed by independent advisors to farmers. During the last two decades, fertilizer companies, animal nutrition providers and plant protection providers also make fertilization schemes, while the former state-paid agricultural advisors have become privatized. As a result, farmers can choose nowadays, and they can use different advisory tools.

E. Objectives of this study

Soil fertility is important for crop production and crop quality, environmental quality, biodiversity and nature development, as well as for resource (land, water, energy, fertilizers) use efficiency. Despite its importance, little is known about spatial and temporal variations in soil fertility. In case farmers would strictly follow fertilization recommendations, soil fertility would be quite uniform and on average ‘sufficient’. However, some incidental reports indicate that uniform and sufficient soil fertility levels are not the case. Recent and comprehensive overviews are lacking though.

In the past, overviews have been made of the mean soil fertility of farmers’ fields of The Netherlands, using one or a few selected soil fertility characteristics (e.g. De Vries & Dechering, 1947; Hissink, 1954; Vermeulen & Fey, 1957; Kortleven, 1963). However, there are no comprehensive overviews of spatial variations and of changes over time in these soil fertility parameters. As a consequence, (changes) in soil fertility status is not well-known quantitatively. Insight into temporal trends in soil fertility is useful in order to be able to predict decreasing soil fertility, and if so, to anticipate with policy and measures.

This thesis aims to increase the understanding of spatial variations and changes over time in soil fertility of farmers’ fields in the Netherlands during the last century. More specifically, the thesis addresses the following research questions:

1. Which changes have taken place in soil organic matter contents and soil phosphorus contents of agricultural land during the 20^{th} century, as function of land use, soil type and region?

2. Will mean soil P status develop towards the optimal agricultural range, with a small standard deviation when virgin soil is cultivated with high craftsmanship?
3. How did herbage mineral composition and cattle manure composition respond to changes in mean soil fertility in dairy farming?
4. What are farmers' perceptions and concerns regarding soil fertility?
5. How to improve the usability of fertilization recommendations, using new knowledge?

F. Outline of the thesis

This thesis consists of 8 chapters and a summary. Following the introductory chapter, chapters 2 – 7 deal with specific (stand-alone) research questions about soil fertility in the Netherlands. Chapters 2, 3, 4, and 6 have been published in or accepted by peer-reviewed scientific journals and chapters 5 and 7 have been submitted to such journals. As a consequence, the introduction and discussion sections of these chapters may contain some overlap. Chapter 8 is the general discussion and synthesis.

Chapter 2 focuses on the temporal dynamics in soil organic carbon (SOC) of agricultural land. The central question in this study was whether SOC is decreasing over time due to for example intensification of soil cultivation, restrictions on manure application and global warming.

Chapter 3 deals with changes in soil P status over time. Central questions in this study relate to regional variations in soil P status as a result of regional variations in P surplus. I also investigated the effects of the stepwise lowering of P application limits on soil P status.

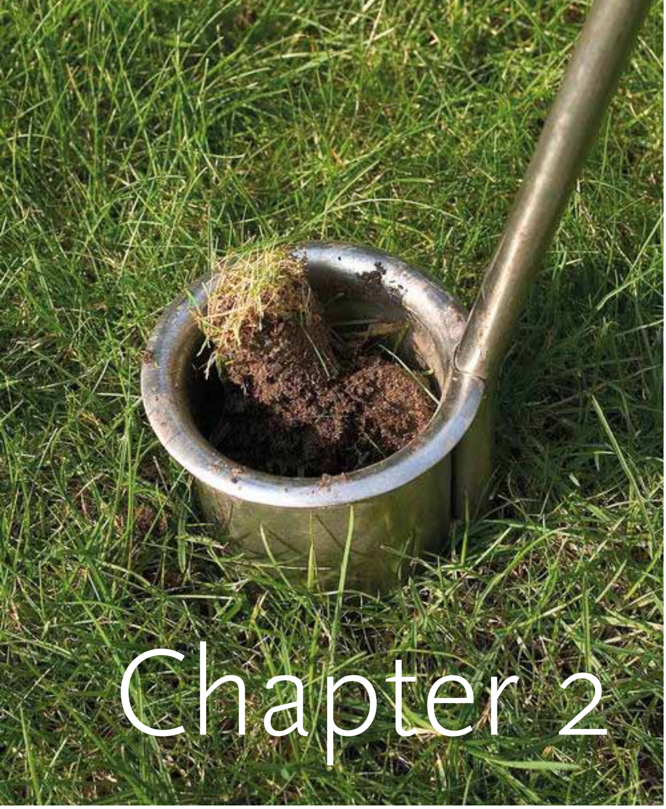
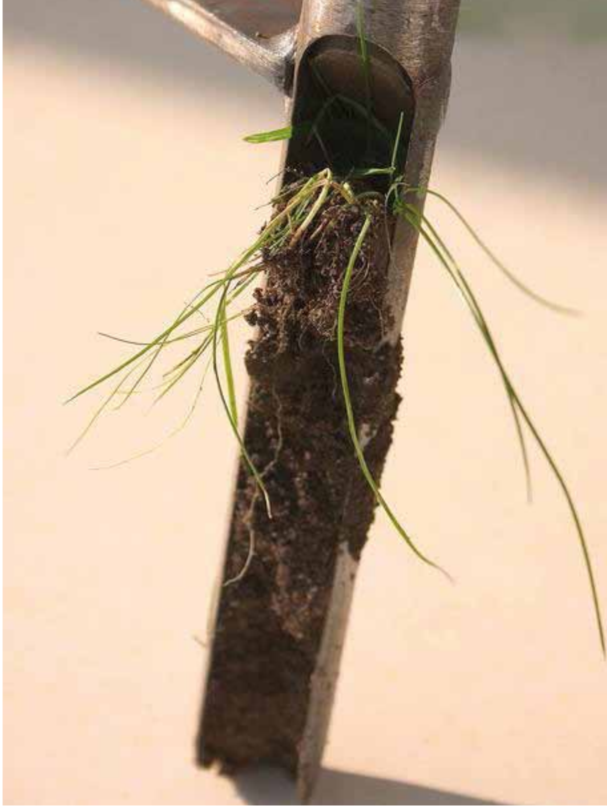
In chapter 4, I test the hypothesis that soil P status will increase to the optimal agronomical ranges, when farmers are well-educated and are not hindered by what has occurred on the land in the past. Changes in soil P status were studied in the Northeast Polder, a recently reclaimed polder with short agricultural history, uniform soil type, and little presence of animal manure.

In chapter 5, I compare soil fertility characteristics of 3 areas with different soil types and examine their relationship with the nutrient content of herbage and manure.

Chapter 6 deals with innovations in soil testing and fertilization recommendations. Most current fertilizer recommendations date from the 1960s and are based on old soil tests. The question is how to modernize these recommendations using new insights, while still utilizing the empirical basis of the recommendations. Note that current recommendations are based on numerous field experiments carried during the last five decades; repeating these experiments would be very costly.

Chapter 7 reports on farmers notions and perceptions about soil fertility and soil testing. I developed and sent out questionnaires to gain more insight in the aims and motives of arable farmers as regards soil testing, fertilizer recommendations and soil fertility in general.

Finally, in chapter 8, the results of this research are synthesised and discussed. The implications of the results are thereby put into a broader perspective.

Chapter 2

SOIL ORGANIC CARBON CONTENTS OF AGRICULTURAL LAND IN THE NETHERLANDS BETWEEN 1984 AND 2004

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Abstract

There is some debate about the likelihood that soil organic carbon (SOC) contents of agricultural land decreases because of global warming and governmental restrictions on animal manure application rates in some countries.

Here, we report on changes in the mean SOC contents of the top soils (0-5 cm) of grassland and the top soil (0-25 cm) of arable land in the Netherlands during the period 1984-2004, using a data base with ~ 2 million results of SOC determinations from farmers' fields. The analyses were made for all agricultural land on mineral soils and for agricultural land in 9 regions with distinct differences in mean soil textures and SOC contents (marine and riverine clay, peaty clays, reclaimed peat soils, and Aeolian sand and loess), and land uses (arable land and permanent grassland). Except for the regions with peaty clay and reclaimed peat soils, samples with SOC >125 g/kg were designated as peat and peaty soils and excluded from the analyses.

Mean SOC content of soils under arable land in 2003 ranged from 13 to 22 g/kg for sand, loess and clay soils to 59 g/kg for reclaimed peat soils. Mean SOC content of soils under permanent grassland in 2003 ranged from 22 to 56 g/kg for sand and clay soils. The difference in mean SOC contents between grassland and arable land is in part related to the difference in sampling depth.

Mean SOC contents of all mineral soils under grasslands and arable land tended to increase annually by 0.10 and 0.08 g/kg, respectively. We observed large differences in mean trends between regions. Regions with relatively low SOC contents tended to accrue C by up to 0.37 g/kg/year, while regions with relatively high SOC contents (e.g., peaty clays) tended to lose C by up to 0.98 g/kg/year.

In conclusion, mean SOC contents of the top part of mineral soils of agricultural land in most regions in the Netherlands tended to increase slightly during the period 1984-2004. This result contrasts with reports from e.g., United Kingdom and Belgium that suggest decreasing C stocks in arable land possibly due to changes in land use and climate.

Key words:

agriculture, arable land, grassland, land use change, soil organic carbon, trends

1. Introduction

Soils contain vast amounts of organic carbon (C). On a global scale, about 1500 Pg (1 Pg = 10^{15} g) is stored in the upper meter of the soil, which is about three times the amount of C in the aboveground biomass and twice the amount of C as CO_2 in the atmosphere (Batjes, 1996; Janzen, 2004). Most of soil C is found in the upper 10 to 20 cm of the soil, and the amount and quality of C in the topsoil is often used as indicator of soil quality and productivity (Allison, 1973; Bauer and Black, 1994; Davidson, 2000). In agriculture, increasing soil organic C (SOC) content is often seen as a desirable objective, especially in organic farming (Mader et al., 2002; Loveland and Webb, 2003; Lal et al., 2004), though the benefits of organic C in soil in terms of fertility arise in part from its decay and not from its accumulation (Janzen; 2004; 2006). Sequestration of C in soils has also been promoted as strategy to mitigate the effects of increasing emissions of greenhouse gases in the atmosphere (Lal et al., 1998; 2001; Janzen, 2004). Sequestration of C in soils can be increased through a wide range of management measures, including reduced tillage (to decrease mineralization), improved rotations and manure application (Freibauer et al., 2004; Smith et al., 2000; 2005).

Though SOC contents are of considerable interest and in principle can be measured easily, there are few monitoring programs that allow systematic analyzing possible changes in SOC in agricultural land in practice (Janssens et al., 2005; Stolbovoy et al., 2005). Current estimates of changes in SOC at national and continental levels are therefore uncertain (Janssens et al., 2003). So far, most estimates are either derived from long-term field experiments (e.g., Jenkinson and Rayner, 1977; Wadman and De Haan, 1997) and/or simulation modelling (Jenkinson et al., 1987; Jenkinson, 1988; Yang and Janssens, 2000; Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004; Vellinga et al, 2004; Smith et al., 2005). Few studies have used repeated inventories for estimating changes in SOC at regional scales (Sleutel et al., 2003; Lettens et al., 2004; Bellamy et al., 2005; Mestdagh et al., 2006).

Some recent studies suggest that SOC of European agricultural land is decreasing (Vleeshouwers and Verhagen, 2002; Sleutel et al., 2003; Bellamy et al., 2005). Such decreases are ascribed to changes in land use, soil cultivation and, possibly, temperature (Davidson and Janssens, 2006). Farmers have concern that decreases in SOC compromises the production capacity of the soil by deterioration of soil physical properties and by impairment of nutrient cycling mechanisms (e.g., Loveland and Webb, 2003). Some arable farmers in the Netherlands are using these arguments to criticize governmental restrictions on the use of animal manure and composts, although these restrictions are meant to regulate the inputs of nutrients and heavy metals. Additions of animal manure and composts are often perceived as inherently desirable.

Agricultural soils in the Netherlands receive relatively large inputs of animal manure, because of the high livestock density (Oenema and Berentsen, 2004). The mean input of effective C, i.e., the C that remains after one year of decomposition (Yang and Janssen, 2000) via animal manure to agricultural land in the Netherlands in the 1990s' has been estimated at ~ 40% of the total input of effective C (Velthof, 2005). Most effective C was derived from crop residues (~ 60%). Less than 2% was derived from composts. Total input of C via animal manure has slightly decreased during the last decade, because of the decreasing livestock density (mainly through a decrease in dairy cow number).

In this paper, we explore the potentials of a data base with ~2 million results of soil analyses from farmers' fields, for assessing changes in SOC of arable land and grassland in the Netherlands during the period 1984-2004. All soil samples have been taken and analysed by one laboratory, on request of farmers to assess the soil fertility level (SOC, pH, plant nutrients) of specific fields. We distinguished the land use types: arable land, grassland and maize land (used for making silage maize to feed cattle). All data for these types of land use and for nine specific regions were analysed for changes in SOC over time and for differences between regions. The analyses were also used to verify whether farmers' concerns about decreasing SOC levels following implementation of governmental restrictions on the use of manure and compost, could be confirmed by data from farmers' fields.

2. Materials and methods

2.1. Site description

The Netherlands (NL) is situated along the North Sea in the western deltas of the rivers Rhine, Meuse and Scheldt and the Northern delta of the Ems (Figure 1). Its surface area is 34,000 km^2, with 470 inhabitants per km^2. The northern and western parts of the Netherlands have marine clay, peaty clay and peat soils, with shallow groundwater levels (0.2-1.0 m below surface level). The southern and eastern parts have glacial and Aeolian sands and Aeolian loess, with shallow to relatively deep groundwater level (1-10 m below surface level). Riverine clay soils dominate along the rivers in the central part. About 60% of the total surface area is agricultural land (20,000 km^2), 15% surface waters, 15% urban and infra-structural area and 10% natural area (forests, heath land, wetlands). Approximately 50% of the agricultural land is intensively managed permanent grasslands, 35% arable land (potatoes, sugar beet, cereals, bulb flowers), 10% maize land (for silage maize), and 5% is horticultural land. The area of agricultural land has declined by on average almost 100 km^2 per year (10,000 ha per year) during the last 50 years (Figure 2). Silage maize was introduced in the late 1960s, at the expense of arable land (for instance rye disappeared) and permanent grassland.

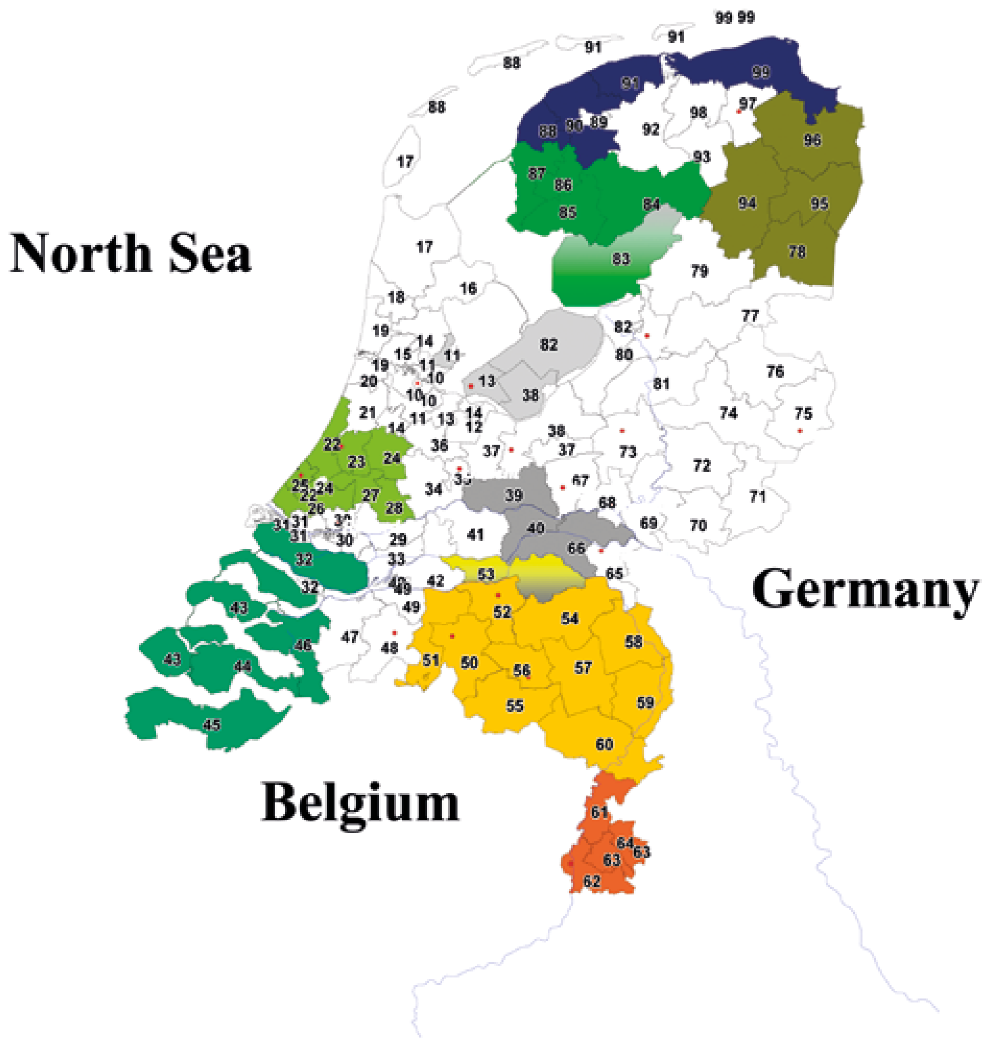

Figure 1. *The Netherlands with the locations of the 9 selected regions. Numbers refer to zip-codes (see Table 1).*

Nine areas were selected for analyzing trends in SOC at regional level (Figure 1). Areas were chosen on the basis of their relative homogeneity in soil type and land use, and identified by the zip code of the farmers' address. Land use on marine clay soils is dominated by arable land, though some areas are used for grassland-based dairy farming as well. Peaty clays are used for dairy farming and thus mainly covered by permanent grasslands, while reclaimed peat soils are mainly used as arable land. Land use on sand and loess in the south is a mixture of permanent grassland, maize land and arable land. A brief characterization of the soils per region is given in Table 1.

Regions	Zip codes	Dominant Land use	Area (ha)	Clay (%)	pH	SOC (g/kg)
1. Marine clay, north	88, 90, 91, 99	Grassland	40544	29 ± 9	6.3 ± 0.8	48 ± 21
2. Marine clay, south-west	32, 43 - 46	Arable land	70914	20 ± 7	7.4 ± 0.3	13 ± 6
3. Marine clay, west-central	11, 13, 38, 82, 83	Arable land	125936	22 ± 10	7.4 ± 0.2	17 ± 9
4. Riverine clay, central	39, 40,53, 66	Grassland	46723	35 ± 12	5.6 ± 0.7	56 ± 26
5. Peaty clay, north	83 - 87	Grassland	152620	27 ± 10	4.9 ± 0.4	133 ± 52
6. Peaty clay, west	22 - 28	Grassland	37466	19 ± 7	5.6 ± 0.8	85 ± 20
7. Reclaimed peat, north-east	78, 94 - 96	Arable land	62593	< 8	4.9 ± 0.3	59 ± 29
8. Sand, south	50 - 60	Grassland	82391	< 8	5.4 ± 0,5	22 ± 8
9. Loess, south	61 - 64	Arable land	13909	14 ± 2	6.6 ± 0.6	14 ± 4

Table 1. Characteristics of the nine studied regions. Means and standard deviations for clay content (particles < 2 µm), soil pH (determined in 1M KCl) and soil organic carbon (SOC) content for the year 2003. The samples analyzed per region ranged from 160 in region 9 to 1405 in region 1 in 2003. The zip codes refer to regions shown in Figure 1.

2.2. Data collection and representativeness

All samples were taken and analyzed by the laboratory for soil and crop analyses Blgg (www.blgg.nl), founded in 1928 as private branch off of the former Institute of Soil Fertility Research in Haren (Harmsen, 1991). Soil samples were analyzed at farmers' request and results documented in reports to farmers only. Summaries (means, median, maximum and minimum values) were incidentally made in the past (e.g., Kortleven, 1962; Hoogerkamp, 1973). From 1984, results were compiled and archived anonymously in an electronic data base. Until 1952, Blgg was the only laboratory that analysed soil samples for farmers. Nowadays, Blgg analyses about 80% of the soil samples offered to the market. Between 1975 and 1995, the number of soil samples was about 150,000 per year. Between 1995 and 2005, the number of samples analyzed by Blgg decreased by about 50%, mainly because farmers became less interested in soil analyses (soil fertility is already high, up-scaling decreased

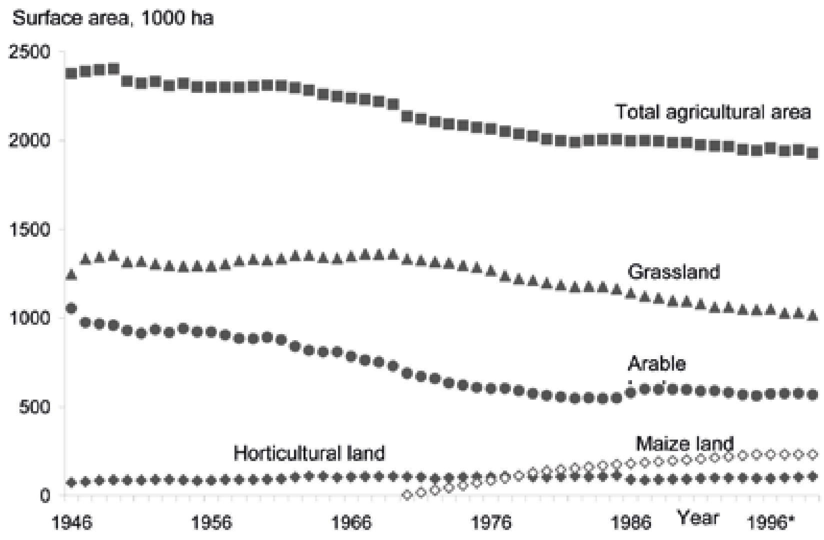

Figure 2 *Changes in the areas of grassland, arable land, horticultural land and maize land between 1950 and 2000.*

number of farms and fields, manure policy focused on nutrient inputs and outputs and not on soil fertility level), and because of competition by other labs. Nowadays, about 20 percent of the farmers have their land analysed every four years. Hence, the number of samples decreased over time, and also varied between years.

Fields were sampled by taking 40 samples when walking in a 'W'-like pattern over the fields (maximum area 2 ha), and these samples were bulked and mixed to one sample for subsequent analysis. Two or more samples were taken for fields larger than 2 ha, depending on the area. Standard sampling depth for permanent grassland was 0-5 cm until 2000 and 0-10 cm thereafter. Standard sampling depth for arable, maize, and horticultural lands is 0-25 cm. Because of the change in standard sampling depth in 2000, we analyzed only data from the period 1984 to 2000 for grassland. For arable land and maize land, we analyzed data from the period 1984-2004.

All samples have been analyzed following standard procedures. In clay and sand soils, SOC was determined by wet oxidation (until 1994), and elemental C analysis following dry combustion. Reference samples were always included, to check the analytical precision throughout the year(s). In organic rich soil (peat soils) with SOC >125 g/kg, SOC was determined by loss on ignition (NEN 5754, 2005), using corrections for inorganic carbonates, and percentage clay in the soil. Loss on ignition (LOI) was converted to SOC by SOC = 0.5 x LOI. There is considerable uncertainty in a conversion factor of LOI to SOC (see

Rosell et al. (2001) for a discussion), which may have affected the quality of the SOC data of peat soils in our study. The overall error of SOC determination (sampling and analyses errors) is estimated at ±5 g/kg for SOC contents < 50 g/kg and at ±10% of the SOC content for SOC contents > 50 g/kg.

2.3. Data processing and statistical analysis

The way in which the soil samples have been taken affects the way the results have to be analyzed as well as the statistical inference (de Gruijter et al., 2006). Our interest is 'changes over time in mean SOC contents within well-defined regions and for specific land uses'. We assumed that the selected data from the database can be analysed as if it was a random sample, and that the errors in the estimates remain small enough to prevent grossly misleading conclusions.

Results of SOC analyses per land use type and/or per region and year were averaged and distributions analyzed for means, medians, skewness and kurtosis, using Genstat (GenStat, 2003) and Microsoft Excel. As we were mainly interested in changes over time (and not so much in differences between regions or in differences between two specific periods), we used simple regression analyses to detect trends in means and medians over years. We corrected for autocorrelation, by using the following statistical model $y_t = a_o + b_1 x + b_2 y_{t-1} + b_3 y_{t-4} + \varepsilon_t$, where y_t is the mean SOC content in year t, a_o is a constant, x is the year number, y_{t-1} is the mean SOC content in year t-1, y_{t-4} is the mean SOC content in year t-4, b_1, b_2, b_3 are coefficients, and ε_t is the error term (de Gruijter et al., 2006). We checked for homogeneity of variance of the mean SOC content between years using Genstat (GenStat, 2003). We also checked for the effects of variations and mean decreases in the number of samples between years on the statistical significance of the changes in SOC over time (using Genstat) and found that these effects were negligible small (because of the large number of samples and the relatively small variations). The average number of samples analyzed per region, land use and year was 1850 (range 100-7500), with larger numbers for large regions.

3. Results

3.1. Mean soil characteristics of the 9 regions in 2003

Table 1 provides an overview of the areas and mean soil characteristics for the dominant land uses of the 9 regions in 2003. Some regions had rather similar soil characteristics (regions 2 and 3), but in general there were distinct differences between regions in mean clay and C contents and in soil pH. The areas of the 9 regions ranged from ~14,000 to 153,000 ha (Table 1)

Mean SOC contents of arable land (0-25 cm) in 2003 ranged from 13 to 17 g/kg for marine clay and loess soils to 59 for reclaimed peat soil (sandy soils). Soils in grassland (0-10 cm) had much higher SOC contents than soils used for arable land. Mean SOC content of permanent grassland on marine and riverine clay soils in 2003 was 48 and 56 g/kg for, respectively (Table 1). The two areas with peaty clays (regions 4 and 5) had much higher SOC contents than the mineral soils. The peaty clays in the west of The Netherlands had a mean SOC of 85 g/kg and those in the north 133 g/kg. The relatively low SOC content of the top soil in peaty clays in the western part of the Netherlands reflects the amendment of the topsoil with sewage and urban wastes, with a lower C content than peat, in the 17^{th} – 20^{th} centuries.

Coefficients of variation of mean SOC contents per regions ranged from 20 to 50% (Table 1). These values compare well with values reported by Sleutel et al. (2003) for Belgium, and reflect heterogeneity in soil types and soil wetness conditions within regions.

3.2. Changes in SOC content of grassland and arable land in The Netherlands

Mean SOC contents of mineral soils (clay and sand soils combined) under grassland (soil layer 0-5cm), arable land and maize land (upper 25 cm) in The Netherlands tended to increase with 0.10, 0.08 and 0.23 g C per kg soil per year during the period 1984-2000, 1984-2004 and 1984-2004, respectively (Figure 3). Variations in annual means were small. Note that samples containing >125 g/kg (i.e. peat samples) had been removed from these sample populations.

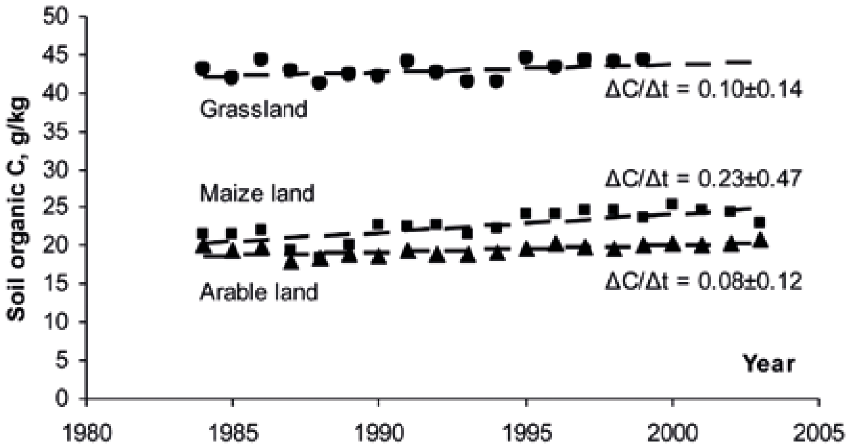

Figure 3. Changes in mean soil organic carbon contents of grassland (period 1984-2000), maize land (1984-2004) and arable land (1984-2004) in the Netherlands. The mean annual change in SOC is indicated as ΔC/Δt, in g/kg/yr.

The apparent increase in the SOC content of maize land is in part related to the increasing area of maize land (Figure 2). The area of silage maize has expanded rapidly from the 1960s onwards, starting in the southern half on sandy soils, but from the 1980s'onwards silage maize has been grown on sandy and clay soils throughout the country at the expense of permanent grassland and arable land. Because of the increasing area of maize land (Figure 2), we excluded maize land from further examination.

Frequency distributions of SOC contents of all mineral soils (sand and clay soils combined) under grassland in the Netherlands were bimodal and skewed (Figure 4). The bimodal character of the frequency distribution of SOC contents reflects the presence of regions with distinct differences in mean SOC contents (see Table 1). Because of the skewed frequency distribution, annual median SOC contents were 6 to 8 g/kg lower than annual mean SOC contents. Over time, skewness tended to decrease, i.e., the percentage samples with relatively low SOC (<25 g/kg) tended to decrease and thus the percentage samples with SOC contents in the range of especially 30-75 g/kg tended to increase. This suggests that soils with low C contents accrued SOC; the number of samples with low SOC contents decreased relative to the number of samples from soils with high SOC contents.

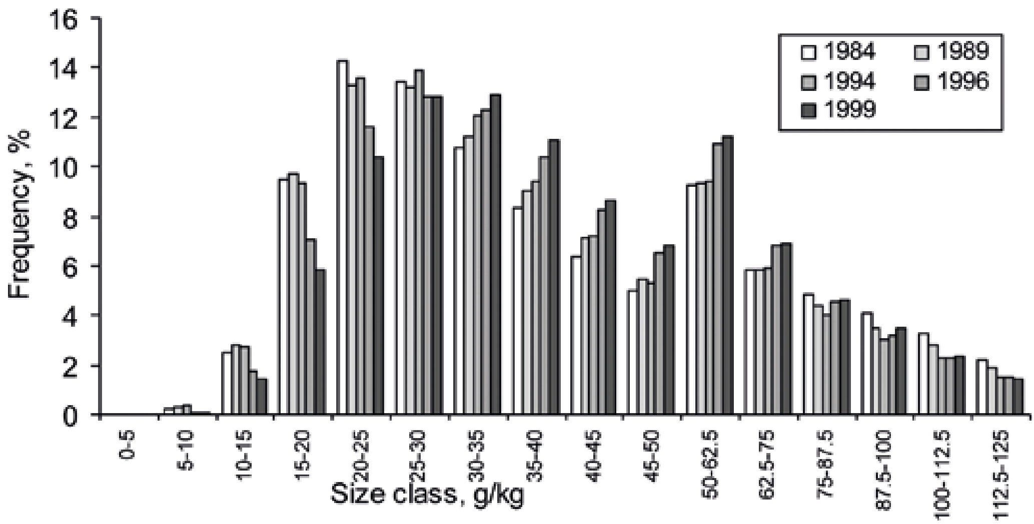

Figure 4. Frequency distributions of SOC classes for grasslands on mineral soils in the Netherlands analyzed in 1984, 1989, 1994, 1996, 1998 and 1999. Note that samples with more than 125 g/kg of C were excluded (see text).

3.3. Changes in SOC contents of grassland and arable land in 9 regions

Regional differences in annual mean changes in SOC were relatively large (Table 2). The mineral soils tended to accrue C, while peaty soils tended to lose C. Annual mean changes in SOC ranged from -0.98±0.81 g/kg for region 5 with peaty clays to +0.37±0.17 g/kg for region 4 with riverine clay soils. Decreases in SOC occurred on soils with relatively high SOC contents (peaty clays), and increases in SOC on soils with relatively low SOC. Increases and decreases in mean SOC occurred both on grassland and arable land.

Frequency distributions of SOC in grassland soils of region 1 are shown in Figure 5. Here, the percentage samples with 20-40 and 40-60 g C per kg increased over time and those with more than 60 g C per kg decreased over time. This pattern is consistent with a decreasing SOC content over time (Table 2). Distributions were broad (low kurtosis) and slightly skewed.

On average, frequency distributions of SOC were more peaked (higher kurtosis) on arable land than on grassland (Table 3). A high kurtosis reflects a narrow distribution and a more homogeneous population of soil samples. Clearly, arable land is found on well-drained and rather homogenous soils, while grassland is situated on both well-drained and poorly drained soils and all soil types. The frequency distribution of SOC contents of arable land in region 2 is shown in Figure 6. About 80% of the samples have SOC contents in the narrow range of 5 to 15 g/kg, while only 20% is in the range of 15 to 50 g/kg. There were no significant trends in SOC content and in distribution patterns in region 2 (Table 2, Figure

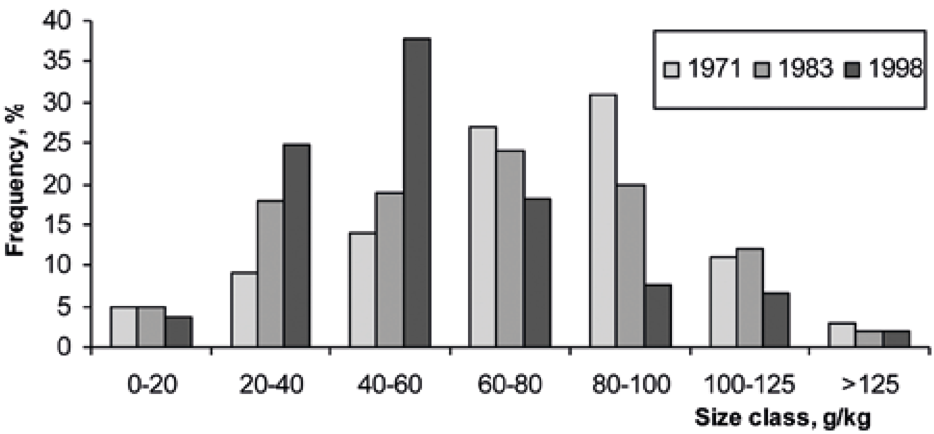

Figure 5. Frequency distributions of SOC classes for grasslands on marine clay soils in region 1 in 1971, 1983 and 1998. Information about samples from 1971 and 1980 were obtained from written records at Blgg

		Summary statistics			
Regions	Land use	Mean	Slope b (± se)	R^2	# samples
1. Marine clay, north	Grassland	57	-0.55 (0.16)	0.46	16849
	Arable land	13	-0.02 (0.04)	0.01	23830
2. Marine clay, south-west	Arable land	12	0.03 (0.02)	0.13	56418
3. Marine clay, central-west	Arable land	21	0.18 (0.12)	0.11	4615
4. Riverine clay, central	Grassland	53	0.37 (0.17)	0.25	12660
5. Peaty clay, north	Grassland	155	-0.98 (0.81)	0.09	9806
6. Peaty clay, west	Grassland	88	-0.27 (0.28)	0.06	5889
7. Reclaimed peat, north-east	Grassland	70	-0.07 (0.36)	0.00	4583
	Arable land	63	0.08 (0.10)	0.04	40497
8. Sand, south	Grassland	24	0.18 (0.05)	0.47	57594
	Arable land	17	0.01 (0.02)	0.02	49344
9. Loess, south	Grassland	33	0.34 (0.11)	0.39	7720
	Arable land	13	0.02 (0.01)	0.10	13977
Netherlands,	Grassland	43	0.10 (0.06)	0.16	589899
	Arable land	20	0.08 (0.02)	0.39	673770
	Maize land	23	0.23 (0.05)	0.58	112168

Table 2. *Overall mean SOC contents (in g/kg), linear regression coefficients (slope b with standard error (se), in g/kg/yr) and Spearman correlation coefficients (R^2), for grassland and arable land of selected regions and The Netherlands. The regression coefficient indicates the mean change of the mean SOC per year. Last column shows number of samples per regions for the period 1984-2004 for arable land and 1984-2000 for grassland.*

6). The sandy soils in the south (region 8) are also homogenous and the frequency distributions of the SOC have a high kurtosis. Region 8 is in the centre of the high-density livestock area, and the application of large amounts of animal manure in the second half of the 20th century may have contributed to the increasing SOC contents in these soils (Table 2). The loess soils of region 9 are also homogeneous (high kurtosis). Region 9 is located near the high-density livestock area, and SOC contents tend to increase over time, in soils under grassland and arable land (Table 2).

Regions	1984/85 Samples #	1984/85 Mean g/kg	1984/85 St dev g/kg	1984/85 Kurtosis g/kg	1999/2000 Samples #	1999/2000 Mean g/kg	1999/2000 St dev g/kg	1999/2000 Kurtosis g/kg
1. Grassland	300	62	3.1	-0.3	534	54	2.6	1.7
2. Arable land	3277	13	0.5	23.1	1541	12	0.5	9.2
3. Arable land	682	20	0.6	-0.0	165	23	0.5	0.2
4. Grassland	723	54	2.6	0.1	383	57	2.1	0.4
5. Grassland	261	156	8.0	-0.9	449	144	5.9	0.2
6. Grassland	322	89	2.5	0.5	100	94	2.9	-0.2
7. Arable land	2517	63	3.3	12.4	1517	64	3.3	12.3
8. Grassland	4293	24	1.0	39.0	1130	26	1.2	67.9
9. Arable land	785	14	0.4	11.6	615	14	0.6	40.8
Grassland	40378	43	2.6	0.7	28260	44	2.3	1.1
Arable land	24716	20	1.5	12.7	32618	20	1.4	10.4

Table 3. *Descriptive statistics of the mean SOC contents for regions in 1984/85 and in 1999/2000.*

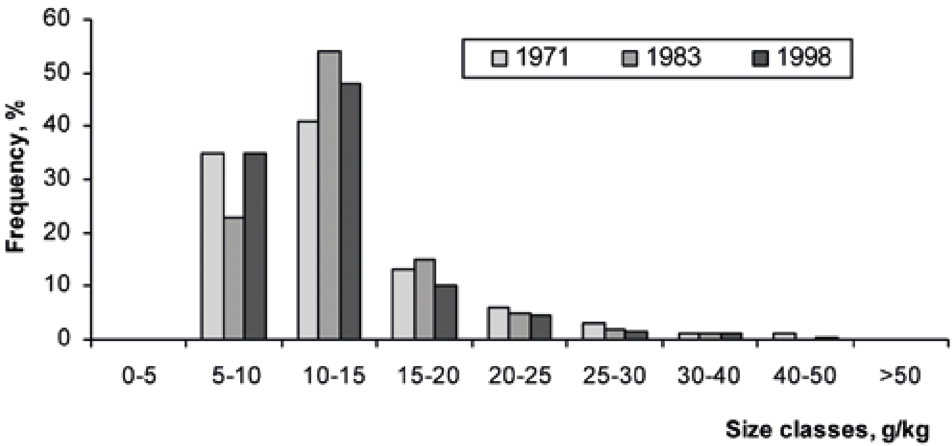

Figure 6. *Frequency distributions of SOC classes for arable land on marine clay soils in region 2 in 1971, 1983 and 1998. Information about samples from 1971 and 1980 were obtained from written records at Blgg.*

4. Discussion

4.1. General trends in SOC contents

Organic C contents in mineral soils under grassland and arable land in the Netherlands tended to increase annually by on average 0.10 and 0.08 g/kg, respectively, during the last two decades. This increase occurred for the dominant land use types (Figure 1), but with large regional differences (Table 2). This result contrasts with reports from United Kingdom (Bellamy et al., 2005) and Belgium (Sleutel et al., 2003), which indicate decreasing SOC contents in agricultural soils by 0-1% per year (relative). Our results are also in contrast with farmers' concern that SOC contents are decreasing because of increasing restrictions on manure and compost applications. Governmental restrictions on the use of animal manure have been tightened from 1984 onwards (Oenema and Berentsen, 2004; Schröder and Neeteson, 2008), and have contributed to a slight decrease over time in organic C input to agricultural soils (Velthof, 2005). However, these restrictions are not reflected in decreasing SOC contents of mineral soils under grasslands and arable land.

Kortleven (1963) summarized results of soil organic matter (SOM) analyses of grassland (0-5 cm) from the same laboratory (Blgg) in the late 1950s, and arrived at a mean of 10.1% for sand and clay soils. They used the so-called Van Bemmelen factor of 1.724 to estimate SOM from SOC data, suggesting that the mean SOC content was 58 g/kg. This value is very close to the overall mean SOC content of 60 g/kg for grassland soils in the period 1984-2000, suggesting that SOC contents of grasslands have been stable or slightly increasing during the last 50 years.

Kortleven (1963) estimated a mean SOC content of 18 g/kg for arable land on sand and clay soils in the 1950s. This estimate is lower than the overall mean of 25.7 g/kg and 19.5 g/kg for arable land under mineral soils without and with corrections of samples with SOC contents >125 g/g, respectively. His estimate is lower than ours, but Kortleven (1963) did not include region 7 in his estimate. This comparison suggests that SOC contents of arable land on mineral clay and sand soils have remained stable or have slightly increased during the last 50 years.

4.2. Regional differences in changes of SOC contents

Mean SOC contents of mineral soils under arable land in regions 2, 3, 8 and 9 compare reasonably well with the mean SOC content of 10 to 20 g/kg in cropland of nearby countries Belgium (Sleutel et al., 2003;), France (Arrouays et al., 2002), England (Bellamy et al., 2005), and other countries in western Europe (Batjes, 1996), despite differences in cropping systems, manure and fertilizer applications and climate. Interestingly, the SOC contents in regions 2, 3, 8 and 9 tended to increase, which is unlike the observed changes in Belgium and England. Changes over time in the SOC of grassland were related to the period-average SOC content; the higher the average SOC content, the larger the decrease in SOC content (Figure 7). The latter observation has been noted also by Bellamy et al. (2005), Sleutel et al., (2003) and Lark et al. (2006). It may reflect the effects of drainage, land use changes and possibly climate change.

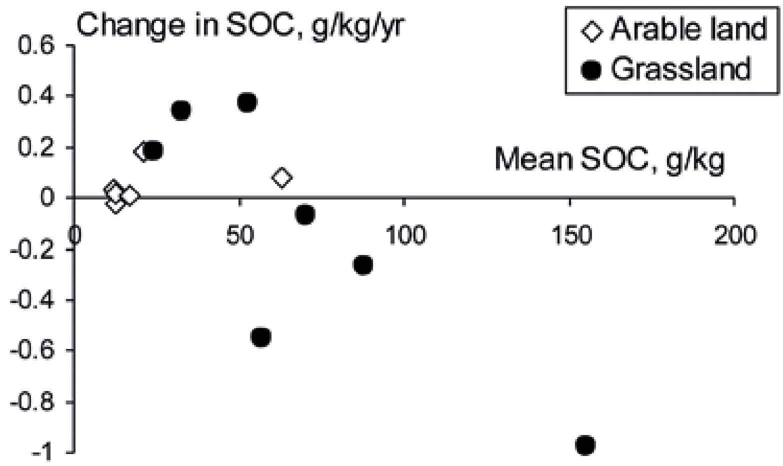

Figure 7. Relationship between mean SOC content (averaged over the whole period) and mean changes in SOC contents for grassland during 1984-2000 and for arable land during 1984-2004, as observed in the nine regions sampled.

The mean SOC content of reclaimed peat soils of region 7 was a factor 2 to 3 higher than those in regions 2, 3, 8 and 9 (Table 1). Our data suggest that the SOC content of the reclaimed soils under arable land have on average slightly increased during the last two decades. This may reflect the use of relatively large amounts of animal manure in this region. It also suggests that the remaining peat residues in the soil have a relatively high resistance to decay.

Grassland soils showed both decreasing trends (regions 1, 5, 6 and 7) and increasing trends (regions 4, 8 and 9) in SOC content (Figure 7). The decrease observed in peaty clay soils with a relatively high SOC content (regions 5, 6 and 7) are likely related to the increased decomposition of SOC (peat) following improved drainage from the first half of the 20th century onwards (Vellinga and Andre, 1999). Decreasing SOC contents in clay soils in region 1 (Figure 5) are more puzzling. Region 1 is situated near the coast of the Wadden Sea and the land use in this area may switch from grassland to arable land (to grow potatoes and bulb flowers) and vice versa, depending in part on market conditions. Exchange of land between arable farms and grassland-based dairy farms have increase during the last decades. Decreasing SOC content in grassland soils in Belgium were also related to changes in land use (Mestdagh et al., 2004; 2005).

Slightly increasing SOC contents of grassland soils were found in regions 4, 8 and 9. Increasing SOC contents suggest that C losses through decay are smaller than C inputs via crop residues and animal manure during the last decades. Inputs of effective organic matter via crop residues and animal manure have been rather stable or were slightly decreasing in the period 1995-2002 (Velthof, 2005). Increasing SOC in grassland soils may also reflect that these soils were previously used as arable land and that they were sown to grassland. Commonly, soils under well-established permanent grassland have much higher SOC content than similar soils under arable land (Hoogerkamp, 1973; Jenkinson, 1988). The SOC content of grassland also depends on the management; grazed pastures have higher SOC content than mown-only grasslands (Hassink and Neeteson, 1991).

4.3. Effects of grassland renovation

Most grassland in The Netherlands is 'permanent' grassland, with Lolium perenne L as dominant grass species, and is intensively managed with 5 to 7 harvests per annum and with a cumulative herbage production of 8,000 to 14,000 kg dry matter per ha per year. However, grassland management has undergone various changes in the 20th century (Bieleman, 2000; Vellinga et al., 2004), which will have influenced the balance of SOC decay and accrual. Major changes include drainage of wet soils, fertilization, soil amelioration and grassland reseeding. Annually, 5 to 10% of the total grassland area is ploughed down and reseeded with higher yielding grass species, with or without growing potatoes or bulbs for one season between ploughing and reseeding (Hoogerkamp, 1973). Vellinga et al (2004) estimated that the increased decay of organic matter due to grassland renovation has emitted 0.4 to 1.1 Mton CO_2 into the atmosphere annually, between 1970 and 2000. This translates to on average 3000 to 9000 kg C per ha or to a SOC loss of 3 to 9 g/kg in the top 10 cm of grassland soils, over this 30-years period. Our data do not reflect decreases in mean SOC content of grasslands of this order (Figure 3). Further, grassland renovation has remained at a steady level of 5 to 10% of the grassland area for at least 50 years (Hoogerkamp, 1973). Hofstee (1985) noted large changes in the area of grassland relative to arable land for the northern area of The Netherlands for the period 1750-1930, but there are no systematic inventories for the whole country for this period.

4.4. Uncertainties

Despite the large number of samples used in this study (nearly 2 million SOC analyses in the period 1984-2004), there is considerable uncertainty in the estimated changes over time. The uncertainty arises from the facts that (i) mean changes in SOC content are small, (ii) selected regions did have inherent soil variability and soil samples were not taken from fixed positions, fields and farms over time, (iii) land use in practice is dynamic, (iv) the number of samples changed over time. We address these uncertainties below.

The mean annual changes in SOC content over time ranged from -0.98 to +0.37 g/kg, which is much less than the accuracy of SOC measurement of individual samples (±5 g/kg for sampling and determination). Hence, a large number of samples are needed to be able to detect significant changes. The standard errors of the linear regression coefficients were proportionally to the mean SOC content and were 1-4 times smaller than the regression coefficients (Table 2). Extending the number of years will contribute to lowering the uncertainty in trend. Saby et al., (2008a) concluded that a time interval of about 10 years is required to detect significant changes in SOC content of soil monitoring sites that are sampled repeatedly.

Soils are variable in space, even within well-defined landscape or soil units. In this study, regions were defined on the basis of overlays of 1:50.000 soil maps (van der Pouw and Finke, 1999; Visschers et al., 2007) and Zip code maps, taking into account that the minimum number of analyses per year within a region is > 100. The sampling locations within these regions have been selected on the basis of requests by farmers. The inherent assumption in our study is that the estimated SOC content, averaged over the samples taken within a region in a year, is approximately equal to the true mean SOC content. We deleted SOC samples containing >125 g/kg in the sample populations from mineral soils, as the number of these organic-rich samples varied from year to year (from 0-10%), decreased over time, and as they had a relatively large effect on the sample mean. The area of peat soils in the Netherlands has greatly diminished over the last centuries due to peat digging as well as increased mineralization following drainage and soil cultivation (de Vries et al., 2008). Hence, peat soils lose SOC, and the decreasing SOC content of the peaty clays in regions 5 and 6 confirm this.

Land use change has a huge effect on SOC contents (e.g., Jenkinson, 1988; Guo and Gifford, 2002; Smith et al., 2000; 2005; Freibauer et al., 2004; Vellinga et al., 2004). After a change in land use from permanent grassland to arable land and vice versa, it may take decades or an even a century before a new equilibrium level is established (Kortleven, 1963; Hoogerkamp, 1973; Jenkinson, 1988). The current land use of the sampling locations is known, but the history of the sampling locations is not always known. The locations may have been in use as grassland or arable land for decades, but may also have been in use for only a few years. Hence, the grassland sample populations include also relatively young grassland and recently resown grasslands. Similarly, the arable land sample populations likely include 'old' and 'young' arable lands. Though the total areas of grassland and arable land depict rather similar and stable trends over time (Figure 2), this does not say much about the dynamics in land use changes. If the exchange of land used for grassland and arable cropping would have increased in frequency with time, then it will tend to globally lower the high mean SOC values of grasslands and to increase the low mean SOC values of arable lands. The sales of grass seed have remained fairly constant during the last few decades, but the conversion of permanent grassland for leys and the areas of leys ploughed up in rotation have slightly increased (Vellinga et al., 2004). Such changes may indeed contribute to a lowering of the mean SOC of grassland and to increasing the mean SOC of arable land. Evidently, the unknown history induces uncertainty in explaining the cause of the observed changes in SOC contents in our data, as well as in many other data.

The fourth factor contributing to possible uncertainty in the observed changes in SOC is the decreasing number of samples over time. Because of the already-high-soil-fertility-status of many agricultural soils, the change to larger fields and farms, and because of the manure policy, various farmers tend to minimize on soil analyses. However, correcting for the decreasing number of samples over time changed the regression coefficients and standard deviations only marginally. Further, it is possible that the decrease in number of samples over time is larger for heavily manured fields than for fields that received the recommended dose, and this variable decrease in the number of samples may contribute to a biased sample population. This possibility should be explored further, for example by re-sampling the data-base which may avoid biases relative to different sampling resolutions in time (e.g., Saby et al., 2008; Lemercier et al., 2008).

5. Conclusions

The data base explored in this study contains vast amounts of soil fertility characteristics of the top soil of agricultural land in the Netherlands from 1930 onward. We have only explored the digitally available SOC data for the period 1984 – 2004 (~2 million data). Our data suggests that SOC contents of mineral soils under both grassland and arable land are slightly increasing, though there are large regional differences. This result contrasts with recent reports (Bellamy et al., 2005; Sleutel et al., 2003; Vleeshouwers and Verhagen, 2003) about SOC depletion in agricultural land in Europe. It also contrasts with farmers' concerns about decreasing SOC, following the implementation of the manure policy which restricts the use of animal manure and composts. Further, the estimated decreases in SOC of peat soils confirm recent soil mapping observations that these soils are vanishing in the Nederlands (de Vries et al., 2008).

The data base allows making regional analyses of changes in SOC content. We made a selection of 9 regions, on the basis of dominant soil types and land uses. Between regions, mean SOC contents of soils under grassland varied by a factor of 3 and those under arable land by a factor of 5, and although the standard deviations of the mean SOC were relatively large (Table 1), the division in regions was helpful in differentiating SOC changes (Table 2).

Evidently, the huge number of analyses data collected in a uniform way over an extended period is a major advantage of the data base analyzed in this study. Until 2004, the sampling locations were not geo-referenced; the sample locations are chosen on farmers' requests and are only known by the field name and the farmers' address. Also, the uncertainty about previous land use of the sampling locations is a limitation of the current data base. In principle, the data base covers soil data from 1928 till present. Evidently, the current data base can also be used as check and extension of the Netherlands soil sampling program, which covers 'only' 2524 sampling points, selected by stratified random sampling (Visschers et al., 2007).

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Chapter 3

CHANGES IN THE SOIL PHOSPHORUS STATUS OF AGRICULTURAL LAND IN THE NETHERLANDS DURING THE 20TH CENTURY

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Abstract

The Netherlands has a high cumulative mean phosphorus (P) balance. In the 20th century, cumulative mean P surpluses were ca. 4500 kg P_2O_5 ha^{-1}. The annual surpluses have levelled off because of manure application limits from 1984 onwards. We report the effect of soil type, land use, and manure policy on changes in soil P of fields in the Netherlands during the 20th century. We used data (>5 million soil P tests) from the soil analysis laboratory BLGG AgroXpertus. Our results show that soil P has increased on average to fairly high and high ratings. Differences between regions and between land use have remained high from the first records in the 1930s; on arable land the increase continued until the end of our study period while on grassland no changes are evident in the last decades. In general regions with high livestock density have high soil P status. Soil P increased in the order bulbfields < grassland < arable land < maize land < horticulture, and in the order loess < clay < peat < sand soils. Spatial variations in P values reflect more the market value of the crops and regional availability of animal manure than P applications. Manure policy since 1984 has resulted in increasingly tight restrictions on P application from manure and fertilisers, but the effects are not yet clearly reflected in changed trends in soil P.

Keywords:

Soil-test database, soil phosphorus, the Netherlands, soil fertility, changes, land use

Introduction

Uptake of P by plants is very sensitive to its concentration in the soil solution (e.g., Barber, 1982; Marschner, 1985; Holford, 1997). This concentration is low, but is buffered by various P fractions in the solid phase through complex desorption-adsorption, dissolution-precipitation and mineralization-immobilization processes (Nye & Tinker, 1977; Ehlert et al., 2003; Van Rotterdam-Los, 2010). These processes are in turn influenced by the presence and activity of plant roots and environmental conditions.

Assessing the availability of P to plants has been a key question in soil fertility research for more than a century (Daubeny, 1845; Dyer, 1894; Anderson, 1960; Sissingh, 1961; Kamprath & Watson, 1980; Sibbensen, 1983; Sims, 1998). Various extractants have been used to determine P availability to crops. Extracted soil P has been related to crop yield response to P fertilizer application as observed in field experiments leading to calibrated P fertiliser recommendations (Sibbensen, 1983; Neyroud & Lischer, 2003). These experiments and analyses form the basis for recommending economically optimal application rates. These recommendations have significantly contributed to alleviating P deficiency in crop production and also to optimizing the agronomic efficiency of P management (Van der Paauw, 1971; Sims et al., 2000). A low soil P status is improved to ample sufficiency through P application while a high soil P status will decrease to adequate sufficiency through limited application. However, these recommendations seem less effective in preventing supra-optimal P applications as the extent of agricultural land with soil P status above the recommended ranges has become significant in many countries. For example, it has been reported that 50% of all arable fields in Sweden have a soil P status corresponding to high or very high (Erikson et al., 1997 in Djodjic et al., 2004). In Belgium about 80% of the arable lands and 60% of grasslands are considered fairly high to very high in soil P (BDB, 2005). In New York State 47% of the tested soil samples were higher than the recommended ranges (Ketterings et al., 2005).

Excessive enrichment of soils with P increases the risk of losses to the aquatic environment through erosion, overland flow and subsurface leaching (Pautler & Sims, 2000; Schoumans & Chardon, 2003; Sims et al., 2000). Enrichment of water bodies with P can lead to eutrophication which then creates serious problems when the water is used for recreation, fishery, drinking and nature conservation (e.g. Csathó et al., 2007). In many countries in the northern hemisphere, agricultural land is regarded as an important, diffuse source of P pollution, contributing about half to the P enrichment of surface waters (Withers et al., 2003). However, the pathways of soil P transfer from agricultural land to surface waters are highly complex and there is large spatial variability in source strength

(Haygarth et al., 2004). This complexity and spatial variability have hindered the development of effective policy measures to decrease P loss from agricultural land. Unwillingness by governments to implement policy measures to restrict P application results from lack of information about variation in soil P status, and by farmers' concerns that limiting P application will reduce crop and animal production. In regions of high soil P status, hesitation in action may also come from concerns that restricting P application will limit the use of animal manure and hence the intensity of livestock production. These barriers will have to be solved because there is increasing concern about the depletion of world P resources (Heffer et al., 2006; Cordell et al., 2009).

In this paper we report changes during the 20th century in soil P of fields in the Netherlands (NL). Agriculture in the Netherlands is characterized by high crop yields, high livestock density and high inputs of fertilizers and imported animal feed (e.g. Oenema & Roest, 1998; Neeteson et al., 2001). Cumulative mean surpluses in the 20th century were ca. 4500 kg P_2O_5 ha^{-1}, but with substantial spatial variations. From 1991 to 2005 the cumulative mean P surplus was almost 1000 kg P_2O_5 ha^{-1}, the highest in Europe and about 200 kg P_2O_5 ha^{-1} more than Belgium (Csathó & Radimszky, 2009). Annual surpluses levelled off following P application limits from 1984 onwards (CBS, 2009). Our main objective was to describe, analyse and understand the changes in soil P in the Netherlands during the 20th century. Specific objectives were to examine (i) the effects of land use and soil type on soil P status, and (ii) the effects of the national manure policy (from 1984 onwards) on soil P status.

Materials and Methods

Agricultural land and soil types

Grass was the major crop in the Netherlands throughout the 20th century (Figure 1). Arable land is mainly used for growing potatoes, cereals, sugar beet, and onions. The main soil type, an acidic sandy soil (Figure 2), is used for grassland and maize silage in the eastern part and for grassland, arable land, and horticulture in the south. Recent carbonate-rich marine clay soils in the southwest, north and in the centre of the country are under arable cultivation. Older, carbonate-poor marine clay soils in the west are used for grassland-based dairy farming. Alluvial soils along the Rhine, Meuse, and Waal are under grassland-based dairy farming on heavy clays and for orchards and tree nurseries on light-textured soils. Reclaimed peat soils are under arable cultivation (potatoes, sugar beet and cereals). Peat soils and peaty clay soils (Histosols) are used for grassland-based dairy farming. Land use on loess in the south is a mixture of grassland, maize, arable land, and horticulture. Growing bulbs, dairy farming and horticulture are practised on the dune sands near the coast.

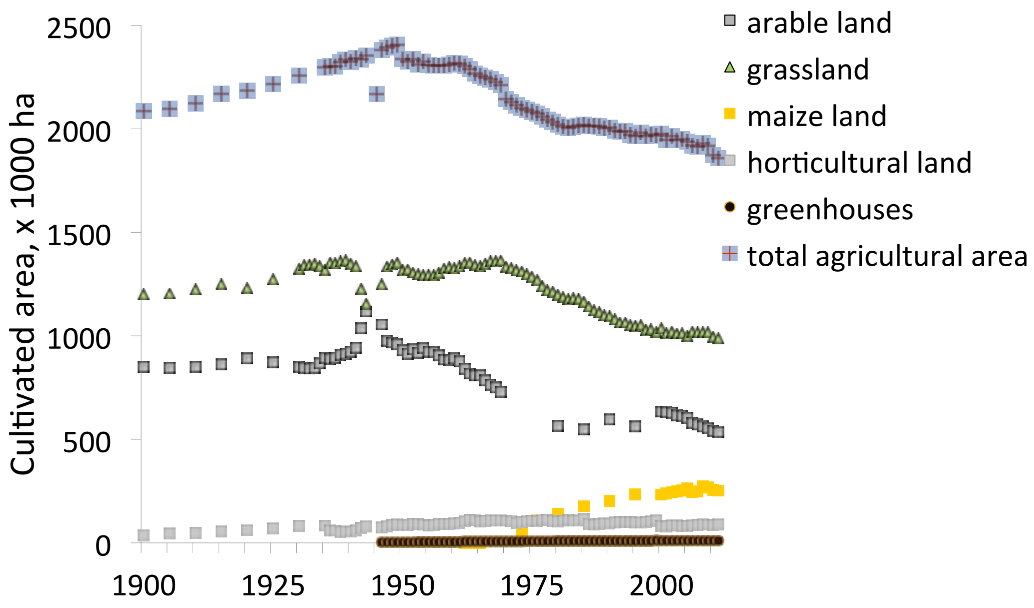

Figure 1. *Changes in the areas of arable land, maize, grassland, horticultural land, and the total agricultural surface area in the Netherlands between 1900 and 2004 (CBS, 2009).*

Soil sampling

Soil analysis has been carried out from 1928 onwards (BLGG.AgroXpertus.nl). Determining the soil P status of farmers' fields became routine for all soil types in the early 1930s. Until 1952 Blgg was the only laboratory in the Netherlands that analysed soil samples at on the request of farmers. Now, Blgg analyses about 80% of all samples. Since 1928 more than 5 million soil P analyses have been done.

Fields were systematically sampled by taking 40 subsamples while walking in a 'W'-like pattern by Blgg technicians. Soil samples were mostly taken just after harvest of the first crops in the second half of August until early spring of the following year (before fertilising). For grassland the soil at 0-5 cm was sampled until 2000 after which it changed to 0-10 cm. Sampling depth for all other crops was related initially to ploughing depth, roughly varying from 15 to 25 cm. From 2000 onwards, > 98% of the samples was taken from 0-25 cm. Before 2008 field locations were referenced by the farmer's name, address and postal code, land use and soil type.

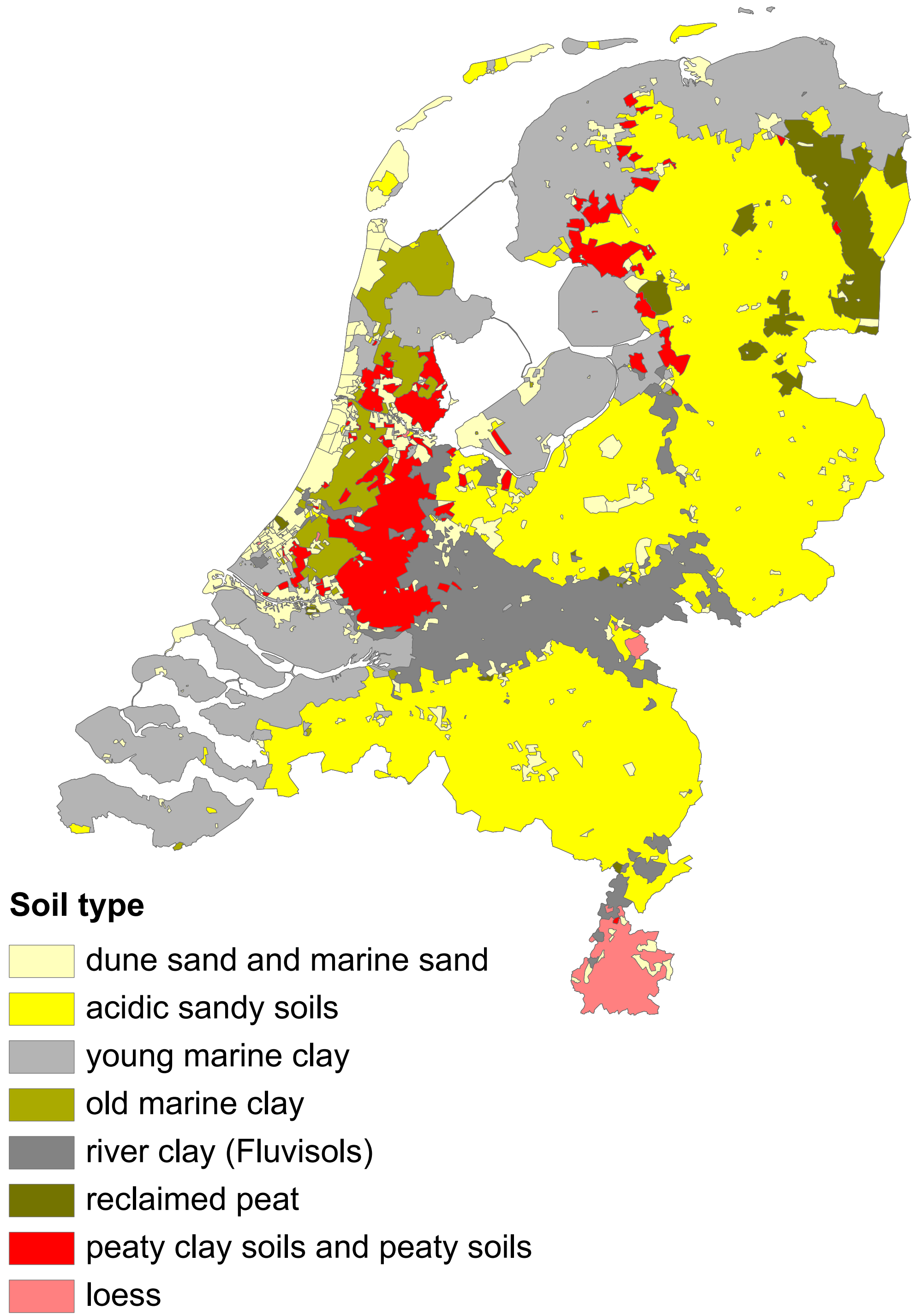

Figure 2. Soil types in the Netherlands.

Table 1. Soil P test methods used by Blgg (The Netherlands).

Soil P test	Unit	Period	Type of determination#	Method (soil : solution ratio)	Detection limit $	Reference
P-water		1928– 1930	P intensity	Phosphoric acid, soluble in water	n.d *	De Vries & Hetteschij, 1935
P-value	mg P_2O_5 100 g^{-1}	1928 - 1968	P intensity	1:10 (w/v) warm water (50°C), 24 h incubation	n.d *	De Vries & Dechering, 1938
P-citric	mg P_2O_5 100 g^{-1}	1933 - 1958	P capacity	1:10 (w/v) 1% citric acid	n.d *	De Vries & Dechering, 1938
Pw-value	mg P_2O_5 l^{-1}	1968 - 2004	P intensity	1:60 (v/v) water (20°C), 22 h incubation, 1 h shaking	4	Sissingh, 1971
P-Al value	mg P_2O_5 100 g^{-1}	1958 - now	P capacity	1:20 (w/v) with 0.1 M ammonium lactate + 0.2 M acetic acid, pH 3.75, 2 h shaking	3	Egnér et al., 1960
P-$CaCl_2$	mg P kg^{-1}	2004 - now	P intensity	1:10 (w/v) with 0.01 M $CaCl_2$, 2 h shaking	0.20	Houba et al., 1998

\# *P intensity: quantifies easily available soil P (De Willigen & Van Noordwijk, 1987; Van Rotterdam – Los, 2010)*

P capacity: quantifies easily available soil P as well as less soluble P fractions

$ *Detection limit during the 1980's and later*

* *n.d.: no data; detection limit was never determined (pers. comm. H. Hartemink, BLGG AgroXpertus)*

Soil analysis

Various extractants have been used to assess soil P status (Table 1). In 1928 the so-called 'P-value' was used based on an extraction with warm water at 50° C. In 1933 a solution of 1% citric acid was introduced as extractant ('P-citric'). Although the P-value/P-citric ratio was helpful, farmers rarely used both methods and usually chose for one or the other (Van der Paauw, 1971). Farmers on sandy soils and reclaimed peat soils used the P-value while farmers on other soil types used P-citric. In 1958 a mixture of 0.1 M ammonium lactate and 0.4 M acetic acid, pH 3.75, was used for the 'P-Al' soil test and replaced the P-citric one (Van der Paauw et al., 1958). P-Al is commonly expressed as mg P_2O_5 100 g^{-1} dry soil (1 mg P = 2.29 g P_2O_5). In 1968 the P-value was replaced by the 'Pw-value', an extraction with water (Van der Paauw, 1971). The Pw-value was used for all non-grassland soils. The P-Al value method was used for grassland and together with the Pw-value also for horticultural land, tree nurseries and bulbfields. In 2004 Blgg replaced the Pw-value method by the 0.01 M calcium chloride method ('P-$CaCl_2$') (Houba et al., 1998; NEN 5704).

The various soil P tests have different extractants and soil: solution ratios and are expressed in different units (Table 1) which make it hard to compare the results from the different methods. For this study, values of P-citric (for grassland) were transformed to P-Al values and the P-value to Pw-values (Van der Paauw et al., 1958). For this paper, we only report P-Al and Pw-values.

Fertilizer recommendations

Farmers receive the results of the soil P tests together with a recommendation for P application (Table 2). From 1984 a target range for Pw-value was recommended for rotations with >25% potatoes. It is recommended to maintain Pw-values in the range of 25-45 mg P_2O_5 l^{-1}, and to apply an amount of P equivalent to the amount of P withdrawn with the harvested crop (estimated at 40-65 kg P_2O_5 ha^{-1} yr^{-1}). With Pw-values >60 it is recommended not to apply any P. For grassland the recommended application in spring ranges from 110 kg P_2O_5 ha^{-1} for the first mowing cut when the P-Al value is 'low' (<18) to 15 kg P_2O_5 ha^{-1} when the P-Al value is 'high' (>55). For late-season harvests (mowing cut or grazing), the recommended applications range from 25 kg P_2O_5 ha^{-1} when the P-Al value is 'low' to 0 kg P_2O_5 ha^{-1} when the P-Al value is 'high'. In all recommendations, P from mineral fertilizer and animal manure is equally valued in terms of its effectiveness.

Table 2. Classification of soil P status on all soil types for arable land based on Pw-values (Anonymous, 1999) and for grassland based on P-Al values (Anonymous, 2002).

Status	Arable land (Pw-value, mg P_2O_5 l^{-1})	Grassland (P-Al value, mg P_2O_5 100 g^{-1})	
		Soil layer 0-5 cm	Soil layer 0-10 cm
Very low	<11	< 18	< 16
Low	11-20	18-29	16-26
Sufficient	21-30	30-39	27-35
Ample sufficient	31-45	40-55	36-50
Fairly high	46-60	Not included	Not included
High	>60	>55	>50

Data processing and statistical analysis

Based on data availability, we distinguished three periods, namely 1928-1970, 1971-1983, and 1984-2004. For the first period, we relied on incidental country-wide overviews as most of the original records of the soil analyses had been lost. For the second period, our interpretations and conclusions are based on frequency distributions of soil P test values as given in Blgg annual reports. A proportion of the original records have been lost, but because the frequency distributions are present, median values can be estimated. For the third period, all original results were available in an electronic database (Microsoft Office Access) together with information about land use, soil type, location (zipcodes or postal codes) and other soil characteristics.

The way by which the samples were been taken affects the selection of statistical technique (De Gruijter et al., 2006). We assumed that the selected data from the database can be analysed as if they were from a random sample, and that the errors in the estimates remain small enough to prevent grossly misleading conclusions. However, in the first period the actual soil P status could be an overestimate as the analyses were requested in general by the better educated and wealthier farmers who used relatively high levels of fertilizer. Similarly, it may be that the measured soil P during the third period may underestimate the actual soil P as farms with a high livestock density and a surplus amount of animal manure may not have requested soil P tests so frequently as they knew that the soil P test values were high. The possible effect of this underestimation is explored in a case study (see below).

Annual means and medians as function of land use from the 2nd (1971-1983) and 3rd periods (1984-2004) were combined and analyzed for changes over time using regression analysis. Since the individual soil tests were available for the 3rd period only, we tested those data for normality using the Shapiro-Wilk-normality tests with the R statistical software (www.r-project.org), thereby testing the hypotheses that kurtosis will increase and skewness will decrease over time when farmers follow the P fertilization recommendations. For further analysis, records of 4 yr were combined (1984-1988 and 1996-2000 (grassland) and 2000-2004 (arable land)) because fields are commonly analyzed every 4 yr. The last period for arable land was 2000-2004 because Blgg ended Pw-value analyses for routine analysis in 2004. The last period for grassland was 1996-2000 because the soil sampling depth altered from 0-5 cm to 0-10 cm in 2000.

We examined changes in national and regional means and medians. Regions were defined on the basis of the postal codes of the fields. Postal zones having less than 20 records (an arbitrary chosen threshold) in the 4-yr-period were excluded from the analysis. This grouping resulted in 1387 and 782 postal zone codes with 20 or more records for grassland and arable land, respectively. The mean number of records per postal zone was 94 for grassland (1996-2000) and 85 for arable land (2000-2004). Changes in the means and medians for each postal zone between the periods 1984-1988 and 1996-2000 (grassland) and 2000-2004 (arable land) were analyzed. Since the data were not normally distributed we analysed changes after a log-transformation, and back-transformed data are presented. We undertook case studies I and II to test the representativeness of our data.

Representativeness of the data, case study I: new clients versus regular clients

In 2005-2006 a total of 16,833 dairy farmers requested soil analyses including soil P. Among this total were 1,904 new clients because of new legislative obligations. We defined new clients as clients who had not analysed their fields in the 10 years prior to 2005-2006. Those new clients submitted 13,536 soil samples; 9,917 from grassland, 1,775 from maize and 1,844 from arable. The records of the grassland and maize fields were compared with the records from grassland and maize fields of the regular clients for 2002-2003, 2003-2004, 2004-2005, and 2005-2006, and the differences were statistically analyzed (*t*-test; $p<0.05$) after log-transformation.

Representativeness of the data, case study II: resampling

Since the number of soil samples varies per year, we also used the resampling method as by Lemercier et al. (2008). The purpose was to find out whether using random subsamples from the database would provide significantly different results compared to the whole database. Case study I included soils under grassland and maize, so we chose for case study II to resample results from arable land on sandy soil using soil data from the 3rd period. For each year we took 6744 soil samples from the database (arable land on sandy soil) and repeated that x15 (per year). From 2003 – 2004 there were 6744 soil samples with all other years having more. We calculated median, average, and the frequency distributions. We compared the results with the values from the complete database (arable land on sandy soil) with *t*-tests.

Results

Mean soil P status in the period 1928-1970

The first overview of the P status of agricultural land on sandy soils was in 1930 (Blgg, 1930) based on samples collected from 1400 fields from May 1929 – May 1930. The soil P status of 56% of the fields was classified as 'not sufficient' and 31% as 'very sufficient' or 'high'. De Vries and Dechering (1938) overviewed the results on the basis of 7849 soil P test values, probably originating from 1935-1937. More than 40% of the samples originated from horti-

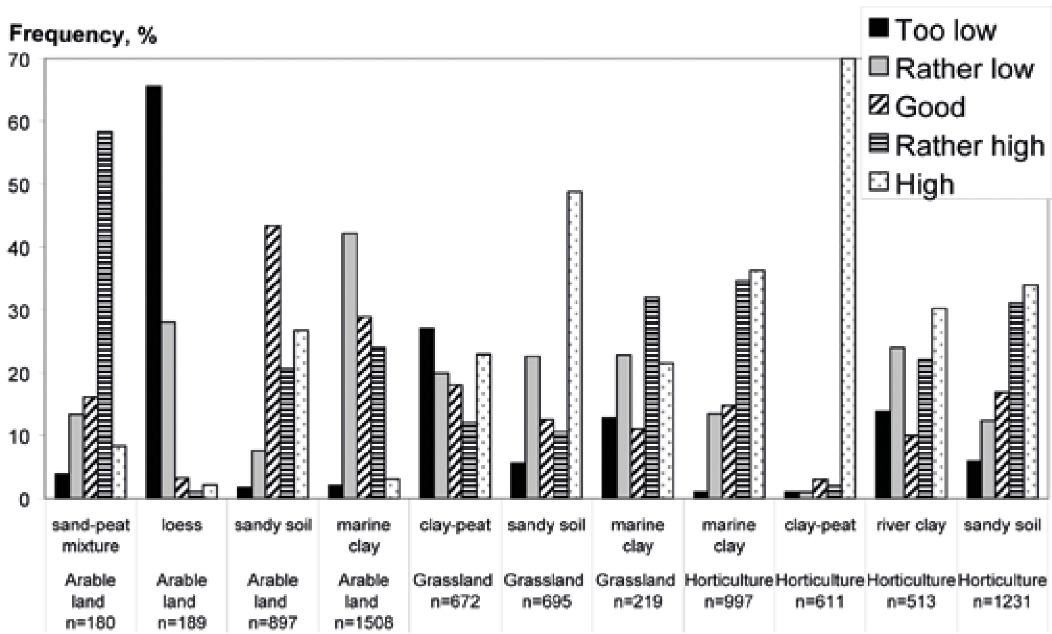

Figure 3. Rating of P status as P-citric for arable land, grassland and horticulture for different soil types for the period 1935 - 1937 (De Vries & Dechering, 1938).

cultural land which covered <5% of the agricultural area. More than half of the samples from horticulture had 'good' to 'high' soil P status (results of transformed P values) (Figure 3). Samples from arable land and grassland had on average a lower P status than those from horticulture. Loess soils had on average the lowest P status (>60% of the samples in the class 'very low') (Figure 3; the results are transformed P values, see Materials and Methods)

Vermeulen and Fey (1957) reviewed the results from ca. 235,000 soil P test values obtained from a survey carried out during 1950 – 1953. Samples were taken from all agricultural land in a systematic grid with ca. 1 sample per 10 ha, and the results were summarized for 183 land use – soil type combinations (with 30 to 8,500 samples per combination). The mean P-Al value of grassland (97,000 samples) was 33 (equivalent to 'sufficient'). The mean Pw-value value of arable land (137,000 samples) was 32 (equivalent to 'ample sufficient'). Riverine clay and loess soils were relatively low in soil P.

Median soil P values for 1971 - 1983

The annual median P-Al values of grassland on sand and marine clay soils ranged between 38 and 49 during 1971-1983 and were quite stable (Figure 4a). The annual median Pw-value of arable land was almost 20 units higher on sand (range 43-52) than on marine clay (range 28-30), and was rather stable between 1971 and 1983 (Figure 4b).

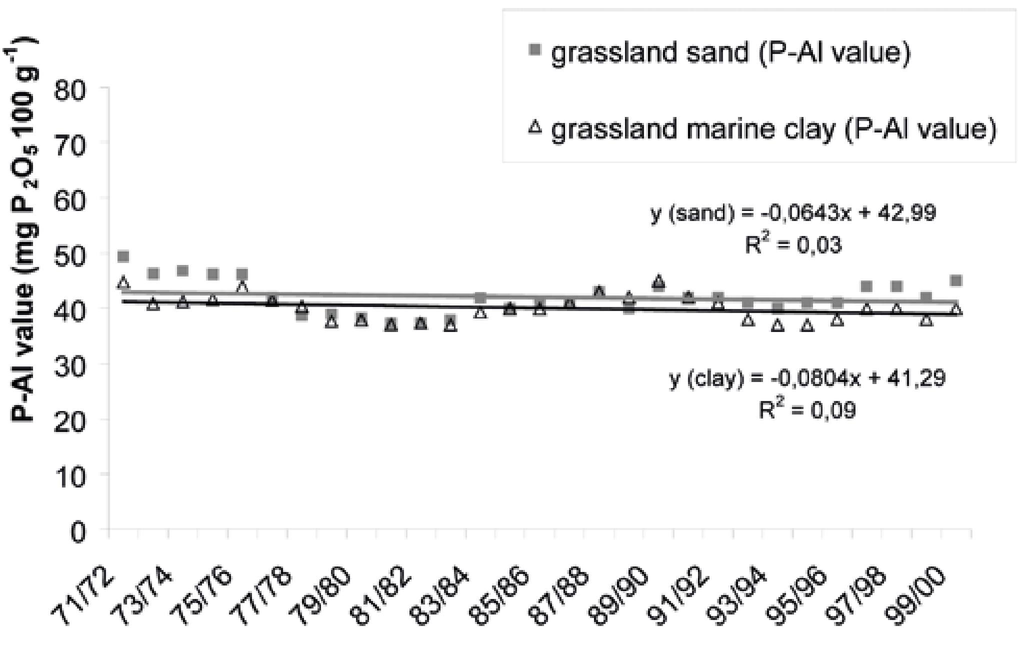

Figure 4a

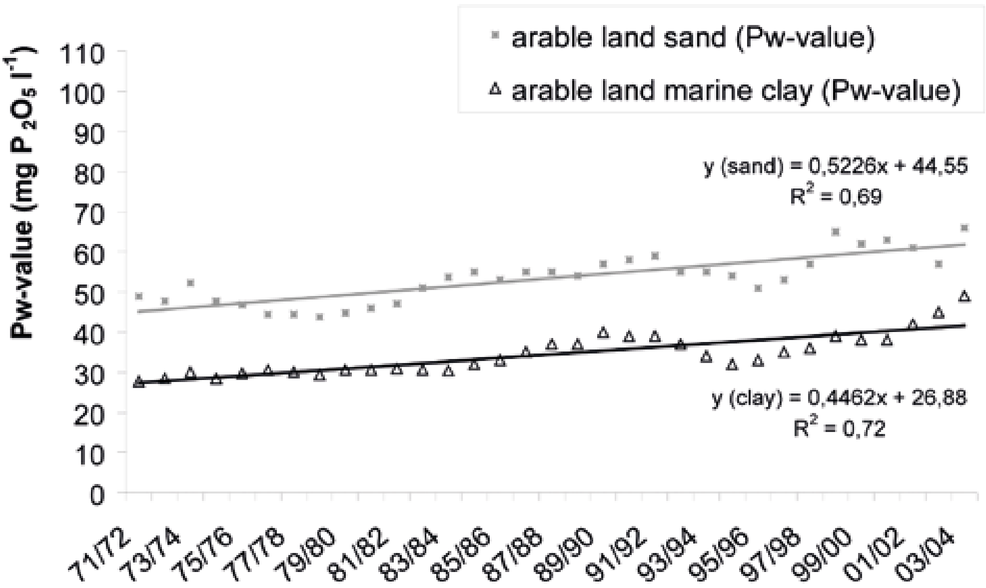

Figure 4b

Figure 4. *Change in median soil P values for grassland (a) and arable land (b) on marine clay and sand during the years 1970 – 2000 and 1970 – 2004, respectively.*

Median soil P values during 1984 – 2004

The median P-Al value of all grassland remained ca. 40 ('ample sufficient') in 1984 - 2000 (Figure 4a). In 1984-1988 a total of 71% of the postal zones had median P-Al values ranging between 30 and 50 which are in the agronomic optimal range, while 14% had a median P-Al value < 30, mainly on loess and river clay. About 2% of the postal zones had median P-Al values > 75. In 1996-2000 a total of 78% postal zones had median P-Al values ranging between 30 and 50, 9% had median P-Al values < 30, and 1.4% >75. Clearly, median soil P values from grasslands vary markedly between postal zones (Figure 5a). Mean differences between 1984-1988 and 1996-2000 in median P-Al values of grassland were relatively small. In 52% of the areas the median values changed <10% between 1984-1988 and 1996-2000. In 34% of the areas there was an increase of >10%, and in 14% there was a decrease of >10%. Areas with a high median P-Al value in 1984-1988 showed a decrease during the 12 yr time span which may reflect the effects of the manure policy, but the spatial pattern of the mean changes was scattered.

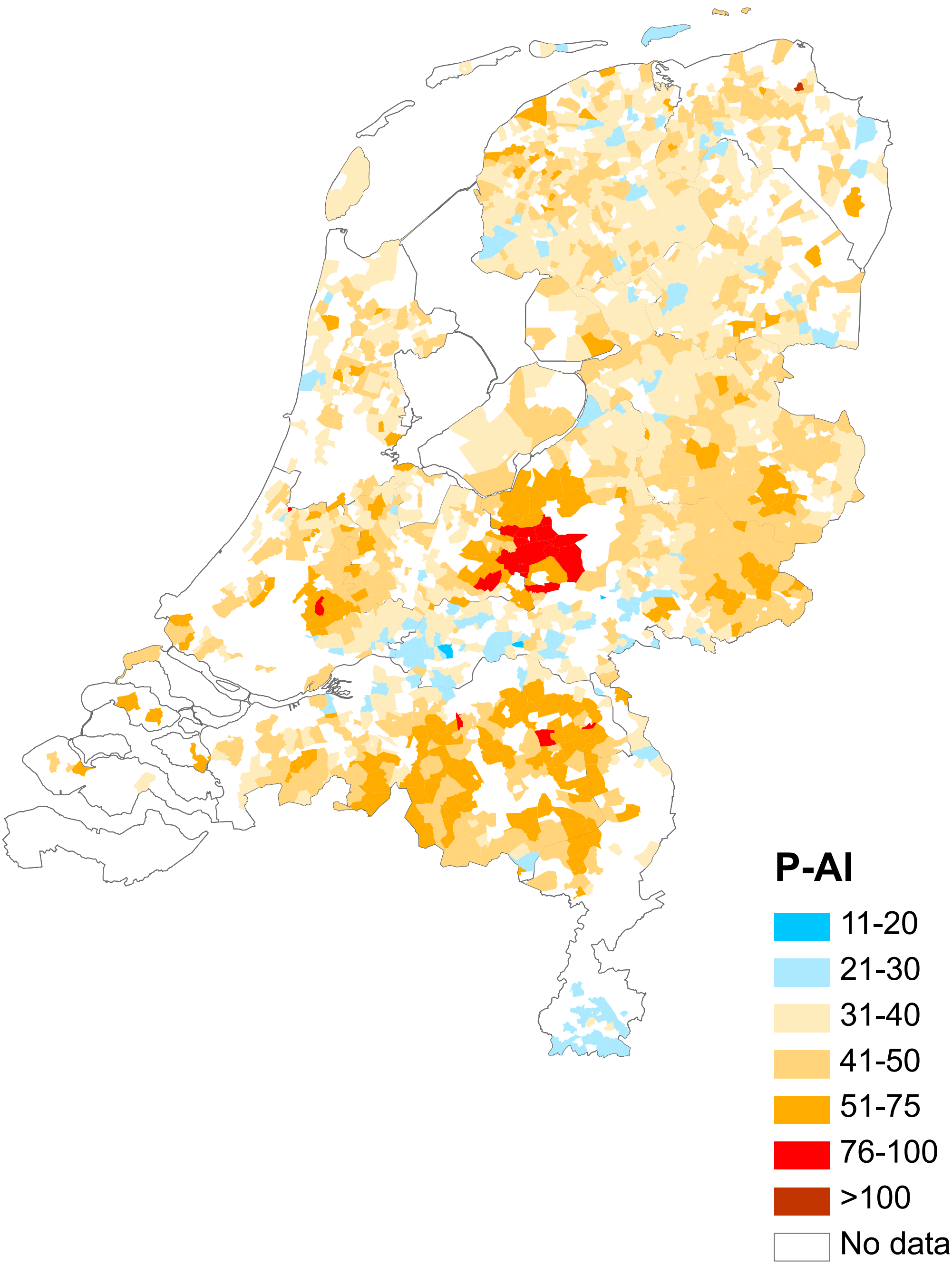

Figure 5.a *Spatial distribution of median P-Al values of grassland (a) and for Pw values of arable land (b) for postal code areas with >20 records during the period 1996-2000 (grassland), and 2000-2004 (arable land).*

The median Pw-value of arable land was 46 during 1984-1988 and increased significantly ($p < 0.01$) to 53 in 2000-2004. Between 1971 – 2004 annual median Pw-values of sand and clay soils used for arable land increased steadily by on average 0.5 units per year (Figure 4b). The median Pw-value was higher on sandy soils in the south than on marine clay soils in the south-west and north (Figure 5b). In 28% of the areas the median values changed <10%, while 58% of the areas had an increase of >10% and 14% a decrease of >10%.

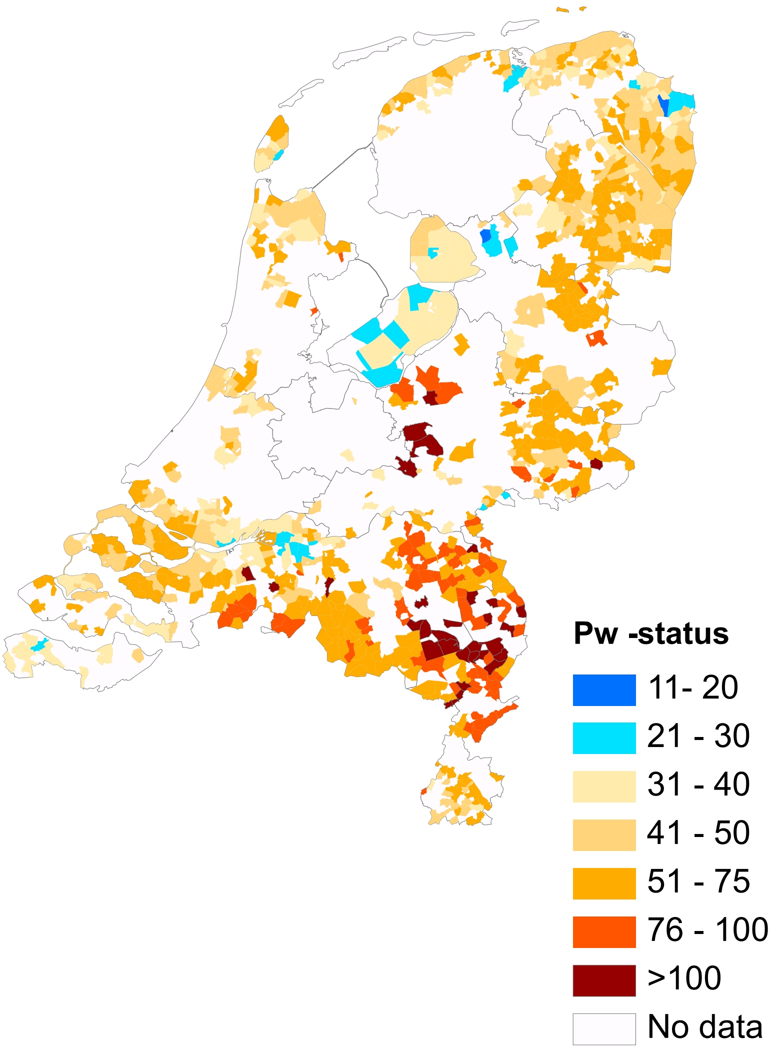

Figure 5.b *Spatial distribution of median P-Al values of grassland (a) and for Pw values of arable land (b) for postal code areas with >20 records during the period 1996-2000 (grassland), and 2000-2004 (arable land).*

The annual median Pw-value of sandy soils under horticulture also increased steadily by on average 0.5 units per year during 1984 – 2004 (Pw-value from 84 to 93), while the annual median P-Al values of these soils increased on average by ca. 0.2 units per year (from 80 to 83). The annual median P-Al value (40) and Pw-value (44) of calcareous dune sands used for bulbs remained remarkably constant during 1984-2004. The annual median Pw-value of maize land (both continuous and in crop rotation) on sandy soils was 60 and did not change much over the last 20 yr (data not shown).

Annual variations in median P-Al and Pw were relatively small for virtually all types of land use – soil type combinations, suggesting that the sample pool was large enough for deriving 'robust' annual median values (Table 3). Still, there are small annual variations which appear to have a cyclical pattern with an amplitude of 5 to 10 units and a cycle of 10 to 15 yr. The cause of this pattern is unclear.

Frequency distributions of soil P values during 1971 – 2004

Frequency distributions of P-Al values of grassland on marine clay soil (Figure 6b) show a slight increase in kurtosis over time; the percentage of records with a P-Al value between 30 and 50 increased from 42 in 1971-1975 to 48% in 1996-2000, while the number of soil samples with P-Al values < 20 decreased from 7 to 4.5%. Similar changes were observed for grassland on sandy soils; the median value remained constant, and kurtosis increased (Figure 6a).

Frequency distributions of Pw-value data of arable lands on sandy soil have low kurtosis and show an increasing positive skewness over time (Figure 6d). The number of records with a Pw-value > 99 increased from ca. 8% in 1971-1975 to ca. 18% in 2000-2004. Records with a Pw-value in the agronomic optimal range (Pw-value 30 – 50) decreased from 29 to 24%, and the number below the optimal range decreased from 24 to 10%. In contrast, the frequency distribution of Pw-values of arable land on marine clay has high kurtosis and relatively low skewness (Figure 6c). The number of records with a Pw-value in the optimal range (Pw-value 30 – 50) increased from 30 to 43%, and below that the range decreased from 57 to 20%.

Only 10% of the records from horticulture on sandy soils have Pw-values in the current optimal range (Pw-value 30 – 50), 3% are below and ca. 85% are above the optimal range (Figure 6e). It should be noted that the recommended optimum Pw-value range was 71 – 90 before 2003 (Anonymous, 1999). In 2000 – 2004, 55% of the records had Pw-values above 90, i.e. above the previous optimal range. The median values significantly increased between 1984-1988 and 2000-2004, kurtosis remained low and skewness high. Frequency distribution of Pw-values of calcareous dune sand used for bulbs remained rather con-

Table 3. *Descriptive statistics (median, mean (results after log-back transformation), standard deviation and number of soil samples) of soil P status for 1984 – 1988#, and the change in soil P status from 1984-2000 or from 1984-2004.*

		P-Al value (mg P_2O_5 100 g^{-1} d.w. soil)						
Sector	Soil Type	Median	Mean	st. dev	n	years	slope	r^2
Grassland	sand	41	41	24.4	110,000	1984-2000	0.17*	0.25
Grassland	marine clay	41	41	22.5	31,000	1984-2000	-0.22	0.22
Horticulture	sand	80	80	38.6	7,900	1984-2004	0.18	0.26
Bulb flower land	dune sand	40	40	21.1	2,400	1984-2004	-0.04	0.00

		Pw-value (mg P_2O_5 l^{-1} d.w. soil)						
Sector	Soil Type	Median	Mean	st .dev	n	years	slope	r^2
Arable land	sand	54	54	41.6	71,000	1984-2004	0.44*	0.38
Arable land	marine clay	34	34	16.9	50,000	1984-2004	0.45*	0.38
Horticulture	sand	84	84	49.6	7,900	1984-2004	0.47*	0.31
Bulb flower land	dune sand	45	44	20.6	2,400	1984-2004	-0.01	0.00
Continuous maize	sand	69	68#	49#	3,400#	1988-2004	-0.99*	0.80

* *The slope was significant ($p<0.05$).*

For continuous maize the descriptive statistics are from 1988-1989, and the change in soil status is from 1988-2004.

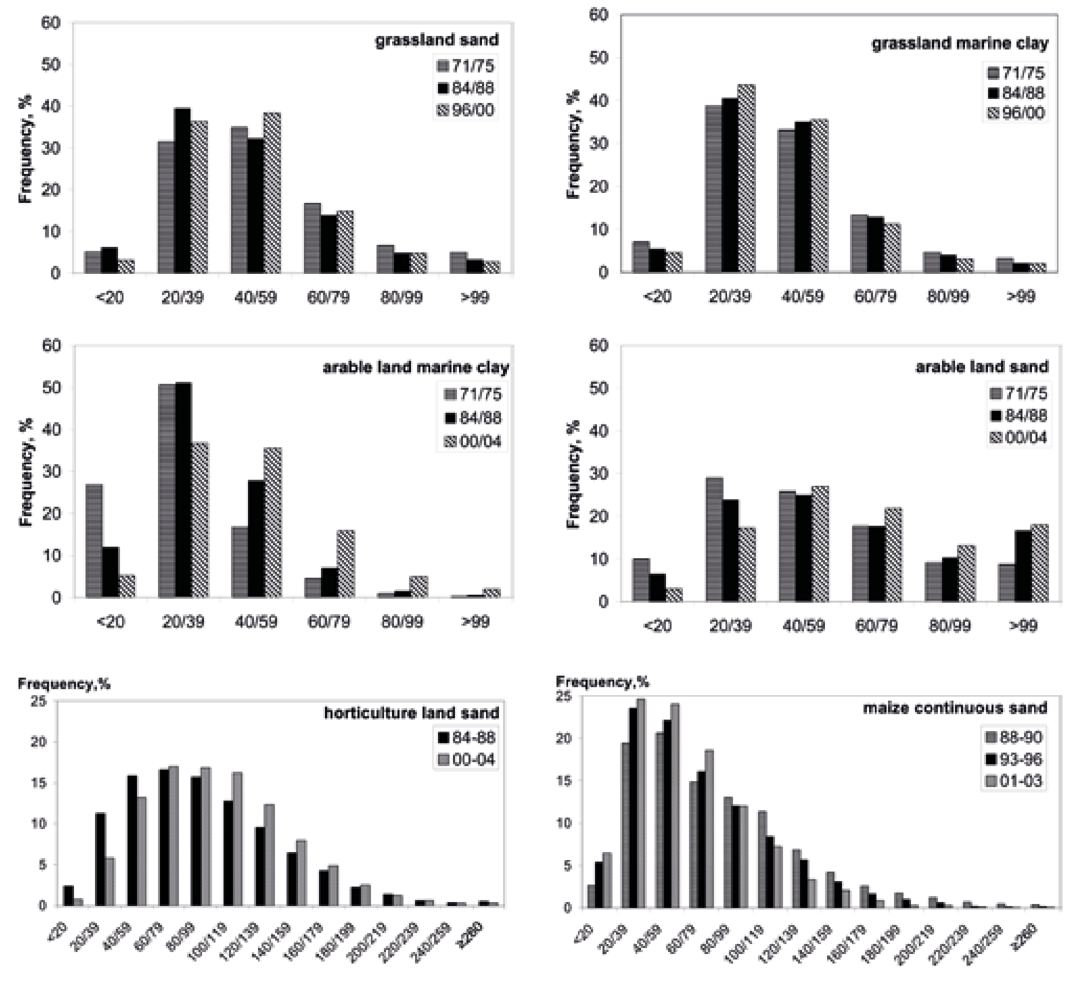

Figure 6. Frequency distribution of soil P values for 2 or 3 periods, for grassland on sand (a), and marine clay (b), arable land on marine clay (c), and sand (d), horticulture on sand (e),) and continuous maize on sand (f).

stant between 1984-1988 and 2000-2004; kurtosis was relatively high and skewness relatively low. Roughly 45% of the records were in the optimal range, ca. 18% below and 37% above the optimal range (data not given).

The frequency distribution of Pw-values of sandy soils used for continuous production of maize silage has low kurtosis and a high positive skewness. About 20-25% of the records are in the optimal range, 15% below and 60 to 65% above the optimal range. The percentage Pw-values > 99 decreased from 30% in 1988-1990 to 15% in 2001-2003.

Case-study I

From the first case-study it was possible to verify whether farmers' fields not tested for the last 10 yr by the Blgg laboratory have significantly different soil P test values from farmers' fields that are regularly analyzed (Table 4). The 'new' fields have significantly higher median P-Al values. The shape of the frequency distributions of the P-Al values is rather similar although the frequency distribution of the 'new' fields is flatter and there are more P-Al values in the higher classes (i.e. lower kurtosis, higher skewness). Results for land under maize (Table 4) and other arable uses (not shown) are quite similar. These results indicate that the soil P test records of Blgg during the last years may slightly underestimate the 'true' median soil P values for grassland, arable land and land used for maize silage production.

Case-study II

In none of the 20 years, medians based on the re-sampled database (arable land on sandy soil) are significantly different ($p<0.01$) from the annual median Pw-value based on the original database. We conclude that re-sampling did not lead to different annual median values.

Discussion

Current soil P status

The current median P values are classified as 'ample sufficient' for grassland, 'fairly high' for arable land and 'high' for horticultural land. There are significant regional differences (Figures 5a and 5b) which are related to differences in soil type, land use, and livestock density. Median soil P values increase in the order loess < clay < peat < sandy soils. Furthermore, soil P values of sandy soils increase in the order grassland < arable land < maize land, with 27, 35, 45, and 80% of the records in the agronomic range 'high' during 1984-2004. The median soil P values of the main land use types reflect to some extent the response of the main crops to soil P levels. However, they are also related to the mean gross economic yield per ha and negatively to the mean farm size. In 2005-2008 the mean gross yield in horticulture (open field), arable farming, dairy farming and pig farming was 18.3, 2.6, 6.3 and 48.8 k€ ha^{-1}, respectively (Boone et al., 2010). The cost of P fertilizer is only a small fraction of the total direct farm cost (ca. 5%), but depends on farm size. Pig farmers had to pay on average 37 k€ per farm to export the surplus amount of pig manure, which is equivalent to 3 to 6 € per kg manure P_2O_5. The relatively low median P values of land used for bulbs with a mean gross economic yield of 26.5 k€ ha^{-1} in 2005-2008 are related in part to the large crop rotation cycle and soil amelioration practices. In summary, the differences between land use types in median soil P are related to the relative cost of P use.

Table 4. *Comparison of P-Al value data of regular Blgg clients (years 2003-2004, 2004-2005, and 2005-2006) and new clients; 2005-2006-'new' (new: they had their fields analysed in 2005-2006, but before that they did not have their soil analysed at Blgg for ≥ 10 year) for grassland (sand and marine clay), and maize land (sand).*

soil and management type	year	mean	St. dev	difference (%) compared to 2005-2006-new	frequency distribution (%; P-Al values categories) 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-99	>99	n
Sand grassland	2003-2004	43.2	22.5	-12.0	0.4	4.5	15.5	23.4	20.1	14.2	8.9	5.2	3.2	1.8	2.8	12332
	2004-2005	43.4	21.3	-11.5	0.1	3.6	15.7	24.4	21.0	14.1	8.8	5.6	2.9	1.3	2.6	11429
	2005-2006	42.9	23.2	- 12.6	0.3	4.0	14.9	22.2	20.5	14.3	9.6	6.0	3.4	1.9	3.0	33461
	2005-2006 'new'	49.1*	27.5	-	0.5	3.9	12.8	16.1	16.8	13.6	12.1	8.6	5.4	3.5	6.6	4745
Marine clay grassland	2003-2004	37.1	22.5	-8.8	0.5	8.2	23.1	26.2	18.8	10.5	5.3	3.1	1.5	0.9	1.9	3833
	2004-2005	34.8	18.9	-14.5	1.2	10.6	24.6	25.6	17.7	10.1	5.0	2.1	1.2	0.5	1.3	3621
	2005-2006	39.1	19.9	- 3.9	0.4	5.6	18.1	25.2	21.3	13.8	7.4	3.7	2.0	1.0	1.5	17323
	2005-2-06 'new'	40.7*	22.0	-	0.8	7.4	17.7	21.0	18.0	14.4	9.7	5.3	2.4	1.1	2.2	1873

soil type	year	mean	st. dev	difference (%) compared to 2005-2006-new	frequency distribution (%; P-Al values categories) 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-99	'>99	n
Sand maize	2003-2004	64.2	29.7	-2.7	0.4	1.7	5.1	8.8	12.6	15.0	14.8	12.9	9.9	6.7	12.2	3835
	2004-2005	60.3	28.4	-8.8	0.1	1.2	5.1	11.2	15.9	16.0	15.3	11.3	8.5	6.1	9.4	3545
	2005-2006	58.3	26.0	-11.8	0.1	1.1	6.6	13.1	15.6	16.2	15.4	11.0	8.4	5.0	7.6	11465
	2005-2006 'new'	66.1*	30.8	–	0.0	1.1	3.9	8.6	11.1	16.1	15.1	14.1	10.6	6.3	13.0	1222

* *All 2005 – 2006 'new' differed significantly from the other years.*

Changes in soil P status over time

Changes in soil P status over time may reflect changes in P balances, in soil-specific P sorption and precipitation reactions and in soil cultivation and management practices (e.g., Koopmans et al., 2004a; Ehlert et al., 2003). Throughout the 20th century the mean P balance of agricultural land in the Netherlands was positive. Unfortunately, there are only accurate P balances at national level and not at regional and sector levels for the 20th century. The P surplus has increased from an average of ca. 25 kg P_2O_5 ha^{-1} yr^{-1} during the first decade of the 20th century to ca. 40 kg ha^{-1} yr^{-1} during the 1950s, and then to ca. 78 kg P_2O_5 $ha^{-1}yr^{-1}$ during the 1980s (CBS, 2009). Thereafter, the P surplus decreased to ca. 40 kg P_2O_5 ha^{-1} in 2008 and will decrease further to 0-20 kg P_2O_5 ha^{-1} in 2015 through the influence of manure policy. This downward trend in P surpluses is as yet not reflected in significant changes in the trends of median soil P values, but may do so in the near future. In contrast, our results show that the median and mean soil P values have increased steadily during the 20th century, but with significant differences between soil types and land use types. Increases were larger for Pw-value of arable land than for P-Al value of grassland; this difference is in part related to the nature of the two extractants and to the nature of the P adsorption/desorption isotherms of the dominant soils under arable land and grassland.

There is a non-linear relationship between P surplus and the increase in soil P based on the buffering capacity of soils (e.g., Koopmans et al., 2004a). Part of the surplus is not reflected in an increase of soil P tests. During the last three decades the median soil P status of grassland (roughly 50% of the total agricultural area) remained constant, while the median soil P status of arable land (roughly 40% of the agricultural area) increased by ca. 15 units. The estimated mean loadings of agricultural soils were 4500 kg P_2O_5 ha^{-1} during 1928 – 2007 and 1200 kg P_2O_5 ha^{-1} during the last three decades. A possible explanation for the relatively small increase in soil P status is the gradual leaching of P from the sampled top soil to the subsoil. Other possible explanations are the frequent reseeding and ploughing of grassland, and the increased plough depth on arable land during the 20th century. Intensively managed grasslands in the Netherlands are resown every 5 yr (Vellinga et al., 2004). This reseeding is often proceeded by ploughing and levelling whereby subsoil low in P is brought to the surface and the P status of the topsoil decreases. A third possible explanation is the further transformation of extractable soil P to non-extractable P forms through precipitation reactions and formation of quasi irreversible sorbed P (e.g. Schoumans et al., 2004). A fourth possible explanation is the underestimation (bias) of mean and median soil P values of land used by livestock farmers during the last decades (Table 4).

It seems that P has been used inefficiently in Dutch agriculture during the 20th century, especially during the second half. This inefficient use is related in part to high livestock density and availability of large amounts of animal manure with mostly unknown P values. It is also related to the fact that fertilizer P has been relatively cheap. A soil with high P status does not damage crop yield and quality. Also, extension services and agricultural research have advised farmers until recently that P does not leach from soil and soil P does not harm the environment; a sufficient to high soil P status is considered 'good agricultural practice'.

Regional variations in soil P status related to land use type

Phosphorus balances at farm level in the Netherlands are related to livestock density; many livestock farms on sandy soils in the south and east are small but have a relatively large number of dairy cows and/or pigs. These animals are fed in part imported animal feed while all manure was applied on the small area of grassland and maize land until manure application limits were introduced in 1984 (Oenema et al., 2005; Schröder & Neeteson, 2008). These farm-type and region-specific manuring practices explain to some extent the differences in soil P levels between land use and soil types. These differences between soil types, regions and land use types in median soil P values were first reported by De Vries & Dechering (1938), Van der Paauw (1948), Vermeulen & Fey (1957) and Neutel (1994). These differences remained throughout the 20th century. Clay soils have lower soil P values than sand ones while loess and riverine clay soils exhibit the lowest values. Median values were highest in horticulture throughout the 20th century and probably also in the 19th century (Mayer, 1895). The frequency distributions of Pw-values of horticultural land have low kurtosis and high positive skewness in the 1930s (Figure 3) and this persisted until 2000-2004 (Figure 6e). This evenness in land use specific soil P status with high values for horticulture is in line with inventories in Brittany (Lemercier et al., 2008), England and Wales (Withers et al., 2001), New York State (Ketterings et al., 2005), North Carolina (Cahoon and Ensign, 2004), Sweden (Erikson et al., 1997) and Finland (Uusitalo et al., 2007). The high P status of horticultural land can be explained by the high P demand of some horticultural crops (Den Dulk, 1959; Anonymous, 1999) as well as by the high economic value of these crops. For centuries, farmers have applied relatively large amounts of P to horticultural land, before the 20th century largely in the form of manure and compost, from the beginning of the 20th century via a combination of manure and P fertilizers.

Effects of the manure policy

As a result of increased awareness in the early 1980s of the risk of euthrophication of surface waters by soils high in P, annual mean P surpluses have decreased steadily (CBS, 2009), but the median and mean soil P values do not yet reflect these changes in soil P loading. Current manure policy aims to ensure that P loading of agricultural soils will decrease further until a 'zero P surplus' has been achieved at national level by 2015 (Anonymous, 2009). Our results indicate that soil P levels will remain relatively high during the first decades due to the slow response to changes in P application. Hence, many agricultural soils will pose a risk to eutrophication of surface waters since soils high in P contribute significant P to runoff as dissolved or particulate-bound P (Pote et al., 1999; Sharpley, 1995). Ultimately, the soil P status of acidic sandy soils may converge to a Pw-value of 20 (Verloop et al., 2010). This is below the agronomic optimal range. However, the final Pw-value will depend on buffering processes which are influenced by soil characteristics and therefore will vary with soil type. This suggests that regular monitoring of soil P is required.

Uncertainties

In this study results from ca. 5 million records of soil P analyses were used with an average of 2.5 records km^{-2} yr^{-1}. This intensity is much higher than in the studies by Lemercier et al. (2008) in Brittany (0.36 km^{-2} yr^{-1}), Wheeler et al. (2004) in New Zealand (0.07 km^{-2} yr^{-1}) and Ketterings et al. (2005) in New York State (0.14 km^{-2} yr^{-1}). But even use of a large data set brings uncertainties as shown by case study I where the estimated means and medians for the last two decades are likely to be underestimates. In case study II results from re-sampling confirmed the changes in soil P as indicated by the median. The overview by Vermeulen and Fey (1957) gives unbiased estimates as these were based on 235,000 samples (>1 sample km^{-2}) taken in a systematic grid during 1950-1953. To reduce uncertainties systematic procedures are recommended. A shortcoming of this current study is that changes in regional patterns of soil P cannot be related to areas of P surplus. Regional patterns of P surpluses are available for the last two decades, but only at a large scale.

Conclusions

1. Values for the current mean and median soil P in the Netherlands can be classed as "ample sufficient" to "fairly high". The median soil P steadily increased during the 20^{th} century, though some land use type - soil type combinations had high P values by the beginning of the 20^{th} century. Variations between regions, land use types and soil types in mean and median soil P have remained high during the 20^{th} century.

2. Current mean and median soil P increase in the order bulbfield < grassland < arable land < maize land < horticulture, and in the order loess < clay < peat < sand soils. This ranking is in part related to the response of the crops to soil P, the gross economic yield per ha and to the duration of the specific land use.

3. The manure policy implemented from 1984 onwards has resulted in declining P balances, but has had as yet little influence on the median and mean soil P. The median soil value has remained rather constant on grassland, steadily increased on arable land, and slightly decreased on horticultural land.
4. Fields not sampled for the last 10 yr have greater soil P than fields that have been sampled and analyzed during the last 10 yr, but there are large variations between the records.
5. There is a relationship between mean P surpluses and mean soil P, but this is complex due to the effects of changes in land use, ploughing depth, soil amelioration practices (e.g. liming, drainage), P leaching and also soil P extraction methods.
6. Uncertainties in databases such as encountered in this study can be addressed in order to monitor soil quality.

Acknowledgements

The authors are grateful for financial support provided by the Ministry of Agriculture, Nature and Food Quality (Program BO-05, Mineralen en Milieukwaliteit). We also thank Frans van Bohemen for making data from 1970-1984 digitally available, Petra van Vliet for the GIS figures, and Mr. H. Neutel for supplying useful insight in relations between agricultural practices and soil P changes.

Chapter 4

DEVELOPMENTS IN SOIL PHOSPHORUS STATUS IN A RECENTLY RECLAIMED POLDER IN THE NETHERLANDS

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Abstract

Compliance with current phosphorus (P) fertilization recommendations would ultimately result in a soil P status of agricultural land in the agronomical optimal range. In practice though there are large variations in soil P status among farms and fields. Our study aimed at increasing the understanding of the cause-effect relationships for these spatial variations in soil P test values. The Northeast Polder in The Netherlands was chosen as study area, because of its characteristics. It was reclaimed from the sea in 1942, has one major soil type (calcareous loam), well-educated farmers, one dominant land use (arable farming) and little pressure to use animal manure. We tested the hypothesis that in this polder mean P status has developed towards the optimal range with a small standard deviation. We analysed available soil P analyses records (>30,000) from the period ~1950 to 2004, and conducted a questionnaire about fertilization practices among farmers.

The soil P(w) values increased steadily and significantly from the agronomical range 'low' to 'ample sufficient' from 1971 to 2004. Variation within and between farms also increased. About 45% of the farmers appear to aim at a soil P status above the agronomical optimal range, and >70% of the farmers indicated that they are uncertain whether the obtained increase in soil P(w) status is actually plant available P.

In conclusion, our hypothesis was rejected: for farmers in our study area, risk avoidance seems the decisive factor for pursuing a soil P status above the agronomical optimal range. If even well-educated farmers question the official fertilizer recommendations and aim at higher levels of soil P fertility, also other farmers worldwide may continue to aim such supra-optimal soil P status. This is undesirable given the diminishing P resources. Possible solutions could be to define more refined P fertilization recommendations and better and more intensified communication of those recommendations to farmers and their advisers.

Keywords

Database • Fertilizer recommendations • Phosphorus • Soil test • Phosphorus resources

Introduction

For decades, fertilization recommendations have been given to farmers especially in developed countries to optimize crop yields (Sinnema, 1824; De Geus, 1967). From the beginning of the 20th century, these fertilization recommendations are often based on chemical soil tests (De Vries & Dechering, 1948; Parker et al. 1951; Voss, 1998). Compliance with soil test based fertilization recommendations would ultimately result in fields with nutrient status in the indicated agronomical optimal range. Increasing the soil nutrient status above the agronomical optimal soil fertility range is considered to be unnecessary (e.g. Otten & Veenstra, 1951; Van der Paauw & Sluijsmans, 1954; Anonymous, 1986; Olfs et al. 2005), because additional fertilization costs are not compensated by additional yield increase. In addition, nutrient losses likely increase strongly when fertilization exceeds optimal application rates (e.g. Delgado & Scalenghe, 2008).

In contrast to the expectations based on soil test based fertilization recommendations, there is large variation between fields in soil phosphorus (P) status in Europe and North America (Ketterings et al. 2005; Lemercier et al. 2008; Wheeler et al. 2004; Csathó et al. 2007; Reijneveld et al. 2010a). Also large differences between fields in soil K status have been reported (Skinner and Todd, 1998; Wheeler et al. 2004). These large differences have often been explained by differences in soil types, land use and management practices, availability of fertilizers and animal manure, and also fertilizer subsidies (e.g., Liu et al. 2007; Wang et al. 2009). Already by the end of the 19th century it was noticed that the lowest soil P test values of horticultural land were higher than the average of arable land in The Netherlands (Mayer, 1895). Evidently, the economic revenues were much higher for horticultural than for arable land, and this provided the incentive to invest relatively more in the soil fertility of horticultural land. The level of education of farmers and the presence of extension services might also explain the differences in the use of fertilization recommendations; regional extension services on the same soil type recommended different amounts of fertilizer for the same crops (W. van Dijk, pers. comm. PPO-WUR, and Th. Van Mierlo, pers. comm. BLGG AgroXpertus) although the recommended optimal agricultural P(w) range was constant from 1970 onwards (Van Dijk, 1999). Risk perception of low-P soil fertility was a reason for aiming at higher soil P fertility status and, in some regions, the appeal in using animal manure may also have conflicted with acting upon fertilization recommendations (Pautler & Sims, 2000; Ketterings et al. 2005; Lemercier et al. 2008). Due to the complexities and confounding factors involved, it is often hard to explain the cause-effect relationships for the large spatial variations in soil P test values. Proper management of P fertilizer is of utmost importance because of the depleting P rock resources (Heffer et al. 2006; Cordell et al. 2009).

Here, we report on temporal changes and spatial variations in soil P test values in a recently reclaimed polder, with one dominant soil type and land use, and with well-educated farmers. The Northeast Polder (in Dutch: Noordoostpolder) was reclaimed from the sea in 1942. Farmers started to grow crops (initially *Phragmites communis* and *Brassica napus,* later arable crop rotations with predominantly wheat, sugar beet and potatoes) from the late 1940s and beginning of the 1950s. Since its reclamation, land use has become more intensive, but has remained predominantly arable cropping. Especially the area of flower bulb growing has increased at the expense of cereal crops. The high quality soils, suitable climate and the well-educated farmers make the Northeast Polder one of the most productive arable cropping areas in Europe, currently with mean wheat and sugar beet yields of more than 9,000 and 77,0000 kg per ha per year, respectively. The general objective of our study was to increase the understanding of spatial variations in soil P test values in the Northeast Polder over time. The study focused on testing the following hypotheses: (1) Following the reclamation, mean soil P status will increase to the agronomical optimum range, and will remain at that level further on; (2) The differences between arable farms in mean soil P test values are small; and (3) The variability within farms in soil P values of the various fields is small and remains small, because the allotment and accessibility of all fields is near perfect.

For testing these hypotheses, we made use of a data base containing the results of soil fertility analyses of farmers' fields in the Northeast Polder during the period 1971 to 2004. In addition, we analyzed the results of a questionnaire about the perception and valuation of soil fertility among a selection of farmers in the Northeast Polder in 2009.

Materials and Methods

Site description

The Netherlands (NL) has about 3,000 polders, which is half of the total number of polders in Europe. Around the year 1625 reclaiming land was most intensive, but polders were still rather small at that time (Van Zwet, 2009). In 1932, the Afsluitdijk (closure dike) was made and transformed the Zuiderzee (a shallow inlet of the North Sea) into a lake (IJsselmeer). Within this lake, three large polders were reclaimed: the Northeast Polder in 1942, with 48,000 ha, Eastern Flevoland in 1957, with 54,000 ha and South Flevoland in 1968 with 43,000 ha.

We selected the Northeast polder for further study, because of the homogenous land use (predominantly arable cropping). Since soil type and history of the former islands Urk and Schokland within the Northeast polder deviates from the reclaimed land, they were excluded from this study. From 1947, land was granted to selected farmers. Most farmers came from the nearby provinces Friesland and North-Holland. Following the storm surge in 1953, farmers also came from the flooded province of Zealand. All farmers were well-trained and educated.

In 2007, more than 80% of the land area was agricultural land (CBS, 2009), with 85% arable land, 5% grassland and 10% horticultural land. About 1% of the area is used for glasshouse horticulture. The main crops in 2004-2008 were sugar beets, ware potatoes, winter cereal, seed potatoes and onions. Grassland is mainly found on soil less suitable for arable land, while the most sandy soils are used for forestry (not considered to be agricultural land here).

The main soil type is carbonate-rich sandy loam with an average clay (particles < 2 μm) content of about 12 %. Most clayey soils are found in the centre, most sandy soils in the northern part (Figure 1).

Clay percentage in the NOP (The Netherlands)

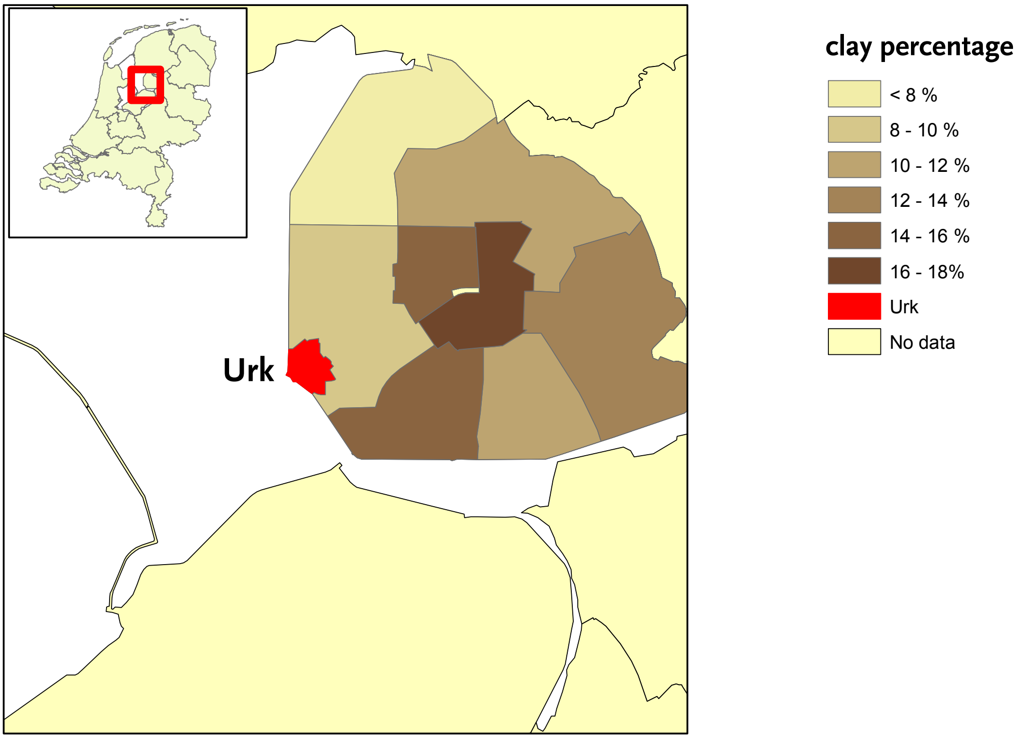

Figure 1. The location of the Northeast Polder in the Netherlands and the average clay content (%) per postal code zone in this reclaimed land. The old isle Urk is also indicated.

Database

We distinguished three periods, based on the availability of soil fertility data. The first period is from the beginning to 1970, for which we rely on summary data in various inventory reports. The second period is from 1971 to 1984, for which we rely on frequency distributions, medians, means, standard deviations as presented in annual Blgg reports. For the third period (1984 – 2004), all original results were available in an electronic database (Microsoft Office Access) together with information about land use, soil type, location (zipcodes or postal codes) and other soil characteristics (see also Reijneveld et al., 2010a). Emphasis of our analysis is on the last two periods, also because of the homogeneity of the data as all samples have been taken and analyzed by the Laboratory for Soil and Crop Analyses BLGG AgroXpertus (http://BLGG.AgroXpertus.nl).

Soil samples were analyzed at farmer's request. Most fields were sampled from August (just after harvest) until February (before fertilization). Soil samples were taken systematically by taking 40 subsamples per field (maximum area 2 ha) while walking in a 'W'-like pattern over the fields. Even when fields are relatively large, for example 10 ha, the sample from 2 ha out of that 10 ha is considered to give a general view of the soil fertility status of that field. Most have farmers have their field analysed every 3, 4, 5, or 6 years (depending on crop rotation). Other farmers have fields analysed every year (mostly before potatoes), while some farmers do not have their fields sampled at all.The depth of soil sampling for arable crops was related to the ploughing depth. In 1984 - 1985, 53% of the soil samples were taken from 0 - 20 cm, 36% from 0 – 22 cm, and 11% from 0-25 cm. In 1999 - 2000, > 98% of the samples was taken from 0-25 cm. Locations of the fields were referenced by the fields' name, the name of the farmer, the address, the postal code, and a characterization of land use and soil type.

Soil P analyses and P fertilization recommendations

In time various extracts have been used to assess the soil P status. For arable land, we used the Pw value, introduced in 1968 (Van der Paauw et al. 1971; Sissingh, 1971), and for grassland the P-Al value, introduced in 1958 (Van der Paauw et al. 1958; Egnér et al. 1960). The Pw test values reflect both the intensity and capacity of the soil to supply P to crop roots; The P-Al value is a so called capacity measurement (Van Rotterdam – Los, 2010). The classification of Pw values and the current P fertilization recommendations for crops grown in the Northeast Polder are presented in Table 1 and the recommendations to improve soil P status to a target range of Pw 25-45 in Table 2. The fertilization recommendations have had some adjustments in the past but the classification of the soil Pw status (from very low to high) has been stable from 1970 until now. In the recommendations, P from mineral fertilizer and animal manure is equally valued in terms of its effectiveness. Farmers are given information about the effectiveness of seed-placement for maize and horticultural crops, it is advised to give 50% - 75% of the recommendation for broadcast applications.

Table 1 *Classification of soil P status for arable soils (from 1970 onwards), and recommended P applications for crops (not for improvements in soil status) (Van Dijk, 1999).*

Status	Pw	Recommended P application per class # (kg P_2O_5 ha^{-1})			
	mg P_2O_5 L^{-1}	1	2	3	4
Very low	<11	185	150	110	60
Low	11-20	170	130	90	40
Sufficient	21-30	135	95	45	0
Ample sufficient	31-45	85	40	0	0
Rather high	46-60	55	0	0	0
High	>60	20	0	0	0
Very high	>80	0	0	0	0

#

Class 1: high P demanding crops: e.g. potatoes and onions.

Class 2: medium to high demanding crops: e.g. sugar beets.

Class 3: medium to low demanding crops: e.g. bulb flowers and barley.

Class 4: low demanding crops: e.g. cereals and rapeseed.

Table 2 *Recommended P application (kg P2O5 ha^{-1}) on arable land for increasing soil Pw to the target range of 25-45 mg P2O5 L-1, as function of initial Pw value (Anonymous, 1986).*

Initial Pw mg P_2O_5 L^{-1}	P application kg P_2O_5 ha^{-1}
1	1500
5	1130
10	780
15	490
20	230
25	0

Statistical analysis

We assumed that the database consists of randomly collected samples. However, since the number and the locations of soil samples vary with time, we checked this assumption using a re-sampling procedure, (e.g. Lemercier et al. 2008). This re-sampling procedure tests whether at random sub-sampling of the database would provide significantly different results.

We present means, medians and ranges over 4-years periods, because farmers' fields are sampled on average every 4 year (following the main crop rotation). Comparisons over time were also made for means and medians of 4-years periods. As the frequency distributions were not normally distributed we made log transformations. We back-transformed the log data to make summaries.

To test the differences in soil P values between arable farms and within farms we only used records of farmers of which > 6 fields had been investigated in the period 1987 – 1991 (further named 1990), and 2000 – 2004 (further named 2000), which included 564 and 745 records, respectively. The variation measured in Pw for 1990 and 2000 was studied by a nested design anova model with fields nested within farmers using command aov of R statistical software (www.r-project.org). The error due to sampling and analysis was estimated in a separate data set with 10 fields sampled/analysed in triplicate. The between-field variance of this data set was 19.1, and it was assumed that this error was constant for the two periods of sampling. Subsequently the variances in Pw originating from between farmers and within farmers was estimated following the method explain in Sokal & Rohlf (1995, p. 278).

A questionnaire about fertilization practices in the Northeast Polder

To obtain more insight in the motivations of farmers in the Northeast Polder concerning soil fertility management and fertilization practices, a questionnaire was developed about soil tests, soil fertility in general, and soil phosphorus in particular. Of the roughly 1000 arable farmers (CBS, 2009) in the Northeast Polder, the questionnaire was sent to 179 randomly chosen farmers.

Results

Sampling intensity and general soil characteristics

Between 1970 and 2000, on average 1483 ± 327 (S.D.) soil samples were taken per year on arable land and 85 ± 24 on grassland (Table 3). The annual variation in

Table 3 *Intensity of soil sampling: Northeast Polder (NOP) versus the Netherlands (NL).*

Region	Period	Arable land (ha)	Number of arable farms	Average area (ha) per farm	Number of arable farms in Blgg data base	Number of samples per ha in 4 years	Number of samples per farm in 4 years
NOP	1984-1988	27,308	1274	21		0.22	4.7
	2000-2004	32,104	938	34	670	0.10	3.4
NL	1984-1988	560,000	67,000	8		0.28	2.3
	2000-2004	627,000	49,006	13	29517	0.09	1.2

Table 4 *Summary statistics of the main soil characteristics of arable land in the Northeast Polder in 2000 – 2004 (for details about the SOM determination; see Reijneveld* et al., *2009).*

2000 – 2004	N-total g kg^{-1} (Combustion in O_2 at 1050 °C)	Pw mg P_2O_5 L^{-1}	P-Al mg P_2O_5 100 g^{-1}	K-HCl mg K_2O 100 g^{-1} (0.1 M HCl + 0.4 M oxalic acid)	K-number (dimensionless)	pH (1 M KCl)	$CaCO_3$ % (Scheibler)	SOM %	Clay %
10 percentile	0.77	24	40.6	11	15	7.2	2.7	1.5	5
Mean	1.23	41.5	56.2	17.5	20.8	7.4	5.9	2.6	12.5
Standard deviation	0.47	16.0	13.8	5.6	5.7	0.2	2.4	1.2	5.6
90-percentile	1.79	63	74	24	27	7.6	8.7	3.6	20
Median	1.16	39	55	17	20	7.4	6.1	2.3	12
Number (n)	453	4348	747	4348	4348	4348	4348	4348	4300

number is related in part to the weather conditions during the soil sampling season; in frosty weather no samples can be taken. Farmers in the Northeast Polder have a higher intensity of soil sampling compared to the Dutch average (Table 3). However, since their farm size is larger, the average per hectare is comparable to the Dutch average.

Median soil pH is 7.5; more than 90% of the records has pH values between 7 and 8. The mean $CaCO_3$ content slightly decreased ($p<0.05$) from 6.2% in 1984 – 1988 to 6.0% in 2000-2004 (Table 4). The soil organic matter (SOM) content of the upper soil layer (0 – 40 cm) ranged between 0.5 and 3.5% (median 2.0%), just after reclamation of the polder in the 1940s (Hissink, 1954). In 2000 – 2004, SOM (0-25 cm) ranged between 1.5 and 3.6 (median 2.3) (Table 4). Between 1971 and 2004, no significant change in median SOM was observed. The median K-status (K-HCl) slightly, but significantly, increased from a median of 14 in 1984-1988 to 17 mg K_2O 100 g^{-1} in 2000-2004.

Changes in soil P status of arable land 1950 – 2004

The first overview of the soil P status in the Northeast Polder (in 1950 – 1953) was made by Vermeulen & Fey (1957). They concluded that arable land had on average a P status near the agronomic optimal range. Van der Schaaf (1967) concluded on the basis of a survey in 1963 – 1964 that 10 – 25% of the fields in the Northeast Polder had a 'too high' soil P test value, 25 – 65% of the fields a 'good' soil P status, and 25 – 50% of the fields a 'too low' soil P status.

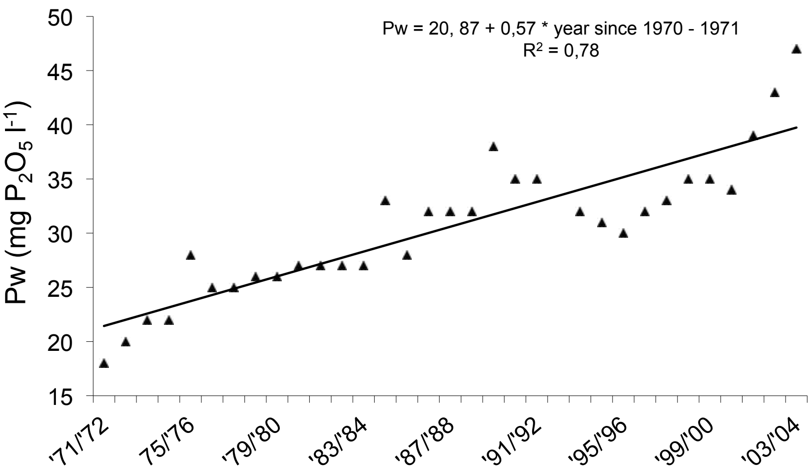

Figure 2. Change in median Pw (mg P2O5 L-1) on arable land in the Northeast Polder in the Netherlands from 1971 - 2004.

Results obtained from our database contrast somewhat with the previous reports. The median Pw value was 20 in 1971 – 1975 and 40 in 2000 – 2004 ($p<0.001$; Figure 2). In the period 1971 – 1975, 86% of the samples had a Pw <30, 13% a Pw within about the agronomic optimal range of 30 – 50, and almost none of the analysed samples were higher. In 1985-1989, 52% of the samples were within the agronomic optimal range and 6% had values above that range. In 2000-2004, 52% of the samples were in the agronomic optimal range, 20% of the fields had a lower Pw status, while 28% was above the agronomic optimal (Figure 3a). The changes over time were all statistical significant ($p<0.01$). Results for grassland are similar to those for arable land; the frequency distribution shifts towards to the right (Figure 3b) and the P-Al increased on average by 0.34 P-Al units yr^{-1}. However, the number of soil samples was considerably lower for grassland than for arable land (350 records were available for grassland and 6630 for arable land during the period 1996 – 2000).

Figure 3a

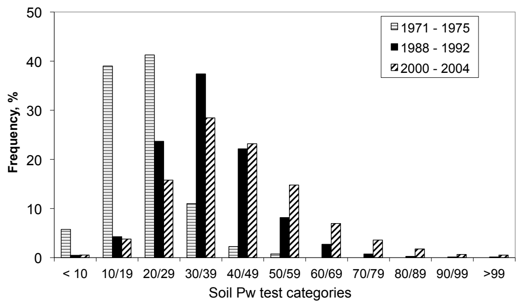

Figure 3b

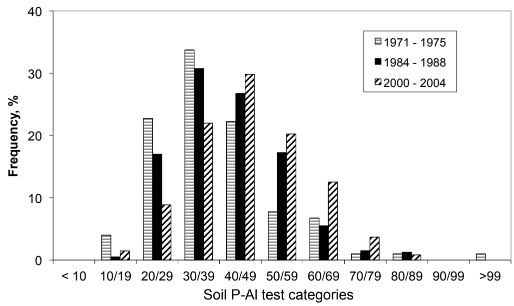

Figure 3. Shift in frequency distribution of (a) soil Pw status on arable land and (b) P-Al status on grassland in the Northeast Polder .

Variations in soil P status between and within farms

We found large variations within and between farms in soil P status (Table 5). For example, fields ranged from 'very low' up to 'high' soil P status on farms with on average a median soil Pw status. The variation within and between farms both increased ($p<0.01$) between 1990 and 2000. In 1990 the variation within and between farms was about the same (not significantly different). However, by 2000 the variation within farms has become, significantly larger than the variation between farms (Figure 4, Table 5).

Table 5 Variation in Pw status (mg P2O5 L-1) between farms, and within farms.

	1987 - 1991 (1990)	2001 - 2004 (2000)
General statistics		
Number of farms with > 6 and < 9 soil samples	73	97
Number of soil samples (records)	564	745
Average number of records per farm	7.7	7.7
Pw status (mg P_2O_5 L^{-1})		
10 percentile	23	25
Mean Pw	34.9	43.2
Standard deviation	10.6	16.5
Median Pw	34	41
90 percentile	48	65
Variance components (S^2)		
Between farms	44.4	102.0
Within farms (between fields)	59.6	162.6
Sampling and analysis	19.1	19.1

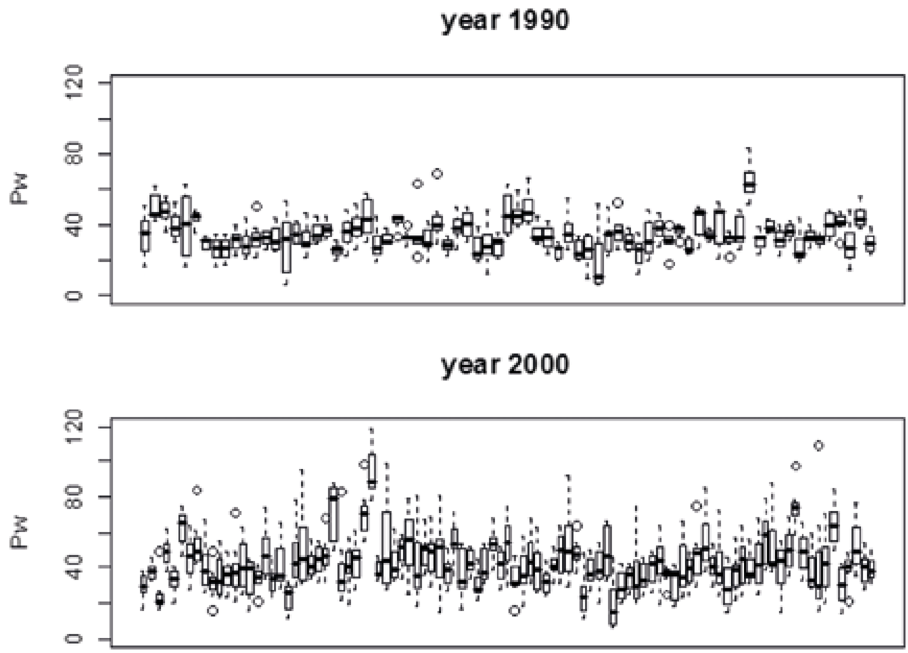

Figure 4. Box plot of variation in Pw status (mg P2O5 L-1) within farms for two periods.

Resampling

In three out of the 20 years (1984 – 2004), medians based on the re-sampled database were significantly different (P<0.01) from the annual medians based on the whole data set (not shown). Differences in median soil P test values were, however, never more than 1 Pw unit when medians were based on a re-sampled set of records versus the whole data base. We conclude that re-sampling did not lead to largely different annual median values.

Questionnaire

The questionnaire was sent to 179 arable farmers (20.5% of the arable farmers in the North-east Polder in 2008). From those farmers, 36 completed the questionnaire, a response of 20%. The farmers were given the possibility to fill in the questionnaire anonymously, but only 7 out of 36 made use of that possibility. The most important results are given below and in Figure 5.

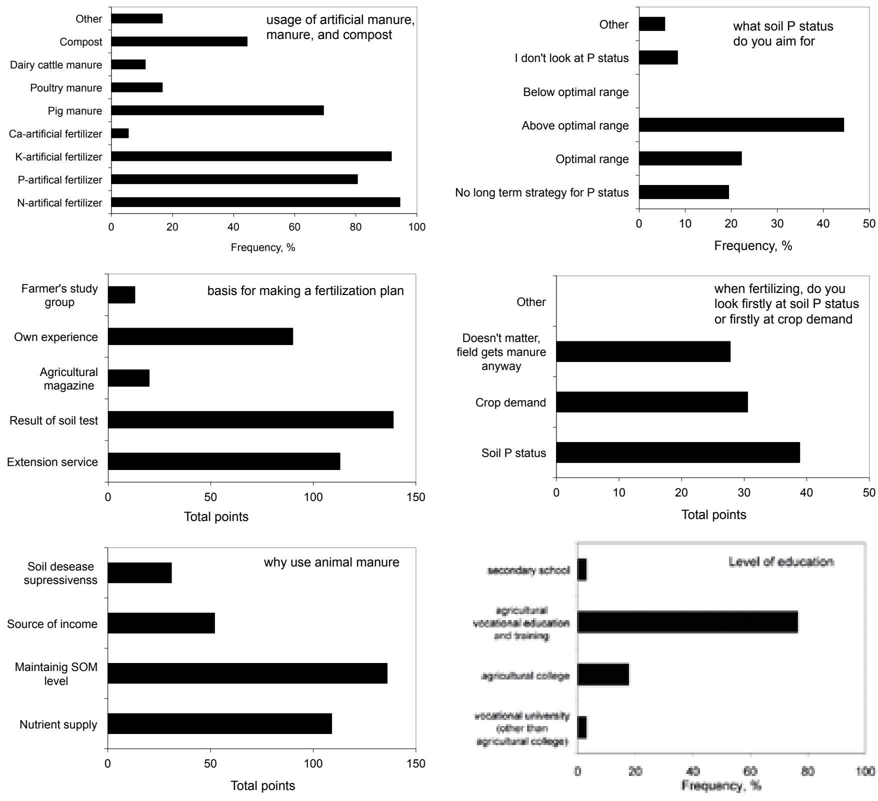

Figure 5. Results of written survey; usage of manure (a), fertilization plan (b), reasons for usage of animal manure (c), soil P status (d), soil P status versus crop demand (e), level of education (f).

The respondents were mostly between 46 – 56 years of age, 20% had a BSc in agriculture, and >70% had a technical education in agriculture (Figure 5f). The respondent's farm size varied from < 20 (6%), 20 – 40 ha (50%), 40 – 80 ha (20%) to > 80 ha (25%). They mostly had a crop rotation of 1:6; e.g. ware potatoes, sugar beets, carrots, ware potatoes, seed onions and winter wheat. About 90% of them had soil samples taken and analyzed in the last 10 years. According to the respondents, the most important result of the soil fertility report is soil P status, followed by soil K status and SOM status. The results of the soil tests are predominantly used for potatoes and onions. When asked about the increase in soil P status from the 1970s till now, >70% state that a high soil Pw test value does not give security about available soil P for crops. Looking forward, arable farmers in the NOP consider soil structure, SOM level, soil life, and soil P status, in that order, to be most important.

Discussion

Fertilization recommendations for P have been designed for optimal economic yields, and compliance with these fertilization recommendations would result in soil P status levels within the optimal agronomical range. We expected this, especially in a highly developed region as the Northeast Polder, where farmers are very well educated.

Soil test P values of the top soil were relatively low before and directly following the reclamation of the Northeast Polder. Three decades after reclamation, in 1971 – 1975, the median Pw was still situated near the agronomical range 'low'. The median Pw increased in the following decades by – on average – 0.57 Pw per year (Figure 2) and by the end of 2000-2004, Pw had doubled to the range 'ample sufficient'. Yet, the median Pw of arable land is less in the Northeast Polder than in the Netherlands as a whole (Reijneveld et al., 2010a). Further, the variation in soil P status is considerable within and between farms and that variation increased over time (Table 5). The results of the questionnaire interestingly suggest that part of the farmers actually aimed at a higher soil P status, most probably because of uncertainties concerning the 'actual' plant available P.

Explanations for high soil P status

It is reasonable to assume that farmers took notice of the results of the soil analyses/written fertilization recommendations, since they find soil P status the most important result of the soil analyses. Above that, farmers tend to value the information of the soil analyses relatively high (Figure 5b). Still, by 2000 – 2004 28% of the fields had Pw values above the optimal level. Reason for this can be several.

Firstly, farmers are unsure about the diagnostic value of the Pw value; >70% of them aim at above-optimal soil P status (Figure 5d). The P extracted by the Pw test represents 'directly' available P (intensity) and partly also 'longer-term' available P (capacity) (Van Noordwijk et al. 1990). The ratio between these two may vary with soil type and also over time. It is well-known that P added from manure and fertilizers tends to become less available to plant with the passing of time (Sample et al. 1980). The process of soluble P becoming less available may occur also in the calcareous soils of the Northeast Polder through P – Ca precipitation reactions (Delgado & Torrent, 2000; Robbins et al. 1999; Siddique & Robinson, 2003; Van Wandruszka, 2006; Cao & Harris, 2008). Further, the inter-annual variations in Pw value are relatively large and the recommended optimum Pw range is relatively wide. All these features may have contributed to aiming at a soil P status above the recommended range. Apparently, there is need of a more trustworthy and refined P fertilization recommendation. Use of two or more P analysis methods have been recommended, because such a combination provides more insight in the actual soil P status (e.g. Kuipers, 1961; Ehlert et al. , 2003; Quintero et al. 2003; Van Rotterdam – Los, 2010).

Secondly, fertilization recommendations are designed for average yields and the Northeast Polder has above average yields. So, farmers may have taken that into consideration by providing more P than recommended. Fertilization recommendations should perhaps be more oriented on regional differences in potential crop yield. The need to improve fertilization recommendations was indicated by several authors, also mentioning that the economic values of the crops have altered since the design of the recommendations (mostly in the 1950's and 1960's), for cost saving reason, for environmental reasons, and for reasons of efficiency of P (e.g. Vos, 1998; Csátho et al. 2009).

Thirdly, the price of P fertilizers was never high compared to crop yields in The Netherlands (except for 2008), and there is no direct agronomical risk of applying P beyond agronomical optimum. Hence, applying more than recommended could be seen as a no-regret security strategy. Moreover, the price of animal manure was not high either; on the contrary, arable farmers are receiving money for taking pig slurry, for most of last two decades. The use of animal manure has been relatively low in the Northeast Polder, because of the risks of negative side effects (e.g., invasion of weeds and other unwanted substances, soil compaction during application). Yet, the use of pig slurry may have contributed to a high soil P status of some fields and farms.

Fourth, there has been a loss of consultation between research and education and counselling since the 1970s. Advisory services have been privatized, and many advisory services are combining advice with direct marketing and supply of farm needs, not necessarily taking the results of the fertilization recommendations into account. This may provide also incentives to apply more P than needed.

From 2006, maximum P application limits have been enforced by the government in the Netherlands, which aim at balanced P fertilization (P input via animal manure and fertilizer equals P output with harvested crops). The application limits are a function of the soil P status; application limits are relatively low when soil P status is high, and vice versa. It is expected that these application limits do indeed lead to a convergence of the soil P status to the target level and also to a decreased variation between farms and within farms.

Explanations for low soil P status

During the period 2000 – 2004, about 5% of the fields had a low P status (Pw < 21 mg P_2O_5 L^{-1}). These fields were more or less randomly distributed over the Northeast Polder. It is unlikely that such fields with low soil P status are related to poor distribution of P fertilizers and/or manure over fields within farms for a long period. It is also unlikely that the low soil P status is related to field-specific soil P binding characteristics, as soils within the polder are rather homogenous. We believe that the low P status of 5% of the fields is related to deep (> 0.5 m) tillage; this was also indicated by some interviewed farmers. Deep tillage is practiced for improving the soil characteristics of the top soil or for improving the soil hydrological and plant rooting properties of the whole soil profile (e.g., for bulb growing). It is unclear why these fields are scattered across the polder.

Other soil characteristics

The increase in soil P is comparable with the increase in K status; the average K status has increased above the optimal range too. Although important, K is almost always regarded as less important than P. So, the increase in P cannot be explained as a side effect of aiming for a high soil K status; it is probably the other way around. The surveyed farmers use both synthetic NPK fertilizers and animal manures (Figure 5), and this combination will have contributed to the increases in soil K-status (and soil P status).

The $CaCO_3$ content has slightly decreased during the last decades, while SOM content remained more or less constant. In contrast, recent reports indicate that arable farms in for example Belgium (Sleutel et al. 2003), England (Bellamy et al. 2005) and southeast Norway (Riley & Bakkegard, 2006) face a decrease in mean SOM contents due to changes in crop rotations, soil cultivation practices and/or climate change.

Uncertainties

Our results and conclusions might be affected by the way our dataset was built up; records from soil samples on farmers' requests. Farmers' intentions towards testing may have changed over time. By using resampling we tried to minimise the uncertainties. Though resampling confirmed the non-resampling results, still uncertainties regarding the dataset remain. These uncertainties have been discussed by several authors (e.g. Wheeler et al. 2004; Uusitalo et al. 2007; Ketterings et al. 2005, Reijneveld et al. 2009, 2010a). Reijneveld et al. (2010a) conducted a test among new clients, i.e. farmers who had not have their fields analysed in 10 years prior to 2005 – 2006, and those who were now obliged (because of legislation) to test their fields. They concluded that the 'new' fields had significantly higher median P-Al values. Fields of regular clients had 4 till 15% lower mean soil P status. However, the shape of the frequency distributions was rather similar when comparing the 'new' and 'regular' results. To overcome these uncertainties we would recommend monitoring programs.

There are also uncertainties related to the questionnaire. Although we got a response of 20%, it could be that only those farmers interested in soil fertility responded. Other mail-out surveys concerning farmer practice and attitude showed a higher response in Australia (Chataway et al. 2003), and a comparable response of farmers by Vanclay and Clyde (1994), and Hayman and Alston (1999). Still, the risk of a biased result remains.

Conclusions

Farming practices on virgin soils in a reclaimed polder have led to an increase in soil fertility during the past 60 years. The number of fields with a low soil P status decreased and the number of fields with a soil P status sufficient and higher increased drastically. The median soil P status increased from 20 (low) in 1971 – 1975 to 40 (ample sufficient) in 2000 – 2004. The median increase in soil P status is in line with the results of the questionnaire which indicates that farmers intended for a soil P status above the recommended range. Furthermore, 70% of the farmers have little confidence in the diagnostic value of P(w) status as indicator for plant available P. These concerns of arable farmers find some evidence in literature; there is need of a more trustworthy and robust method for determining the P status of the soil. .

The variation in soil P status within and between farms also increased over time. So, our hypothesis that P status would rapidly reach the optimal range and would remain within that range without much between-farm variation, cannot be confirmed.

Summarizing, low confidence in the diagnostic value of the P(w) status and risk perception seem important factors for increasing the soil P above the agronomical range in the Northeast Polder. If these farmers aim for high soil P status, other farmers are likely to persuade the same goal. So, the demand for synthetic P is likely to remain high as long as the price is reasonable and there are no legislative restrictions. Such practice may have global implications, and may hit especially resource-poor farmers in Africa, also because of the depleting P rock reserves.

Possible solutions could be a more refined P fertilization recommendations based on among others soil P test that provide more insight and trust in the intensity and capacity soil P characteristics. Improved communication of those fertilizer recommendations to farmers and their advisers is also recommended. Improved P fertilizer application techniques, and more efficient crops might also contribute to diminishing the demand for fertilizer P. Finally, enforcement of P application limits as function of soil P status may be needed as well.

Acknowledgements

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Chapter 5

RELATIONSHIPS BETWEEN SOIL FERTILITY, HERBAGE QUALITY, AND MANURE COMPOSITION ON GRASSLAND-BASED DAIRY FARMS

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Abstract

It is reasonable to expect that compliance with grassland fertilization recommendations in the long run results in optimal soil fertility, and subsequent herbage quality. Here, we evaluate the development of soil, herbage and manure characteristics and their relation over the last decades. We hypothesized that herbage and manure quality are related with soil fertility. We used a large database with results of soil tests, spring forage quality characteristics, and manure analyses, which were made on demand of dairy farmers. We considered the Netherlands as a whole and three selected regions with contrasting soil types (sandy soil, riverine clay, and peaty marine clay). Effects of soil fertility on herbage quality were evident when comparing farms. Farms higher in soil P and K generally have correspondingly higher contents in forage. On average, soil fertility and herbage characteristics were within or just above the agronomical optimal range during the last decades. Herbage crude protein content decreased in all regions during last two decades, which is likely an effect of legislative measures on decreasing the application of N. Selenium (Se) and sulphur (S) contents increased sharply on sandy soils, likely because of increased use of Se and S containing fertilizers. Manure composition did not differ between soil type. In conclusion, at farm level, the element composition of herbage reflected the soil fertility status. The contents of S, P, K, Na, Mg, and Ca in the herbage were all significantly influenced by soil fertility characteristics. Our results emphasize the importance of maintaining soil fertility for high quality roughage production.

Keywords

Soil tests, Soil fertility, Herbage quality, Manure composition, Fertilization, Nutrients, Grassland, Dairy farms

1. Introduction

Grasslands cover large acreages of the world. Managed grasslands are especially found in temperate regions in New Zealand, western Europe, and the southern part of Latin America. These managed grasslands offer high-quality forage to dairy and beef cattle and thereby contribute to our food supply. In favourable regions, forage dry matter (DM) yields of 15 Mg per ha (Drennan et al., 2005) can be achieved, although this requires fertilizer inputs. To optimise production, fertilization recommendations for grassland, based on soil tests, have been developed, mostly during the 1950s and 1960s (Voss, 1998, Anonymous,1989). It is expected that compliance with these recommendations would have resulted in soil fertility characteristics within the optimal ranges. Recommendations for grasslands also consider the element composition of the herbage, as ruminants require the intake of sufficient amounts of essential elements for optimal production and performance. Hence, next to soil fertility, compliance to fertilization recommendations would be expected to result also in optimal levels of essential elements in harvested herbage. Moreover, the composition of the excrements of ruminants reflects the composition of the diet and hence indirectly also the way farmers comply with fertilization recommendations. However, whether this is the case in farmers' practice has not been evaluated in a systematic way so far. It is known that yearly fertilization practices affects the mineral composition of herbage directly (Stout et al., 1977; Edmeades, 2003; Van Soest et al., 1978), but again little work has linked the effects of soil fertility to herbage quality and manure composition under practical conditions.

Here, we test i) whether soil fertility and herbage quality have developed towards the optimal ranges, and ii) how the herbage and manure quality are affected by differences in soil fertility on grassland-based dairy farms in the Netherlands. Thereby, we hypothesized that soils higher in soil fertility will have higher nutrient contents in herbage and manure.

Agriculture in the Netherlands is one of the most productive in the world, which is due in part to its fertile soils. Part of this soil fertility is natural, i.e. inherited from the sea (peaty marine clay soils) or from the river Rhine (riverine clay soils). The fluvial-glacial sandy soils in the east and south of the country had low fertility originally, but have been made fertile by farmers during the last few centuries. Approximately 62% of the agricultural area in the Netherlands is used for dairy farming (50% grassland and 12% fodder crops; CBS, 2012). We tested our hypotheses on grassland-based dairy farms for the whole of the Netherlands and for three contrasting regions as regards soil type (peaty marine clay, riverine clay, and sandy soil).

Soil fertility characteristics change over time due to changes in fertilization practises, for example in response to governmental regulations (e.g. De Clercq et al., 2001; Schröder & Neeteson, 2008). Herbage and manure quality may also vary between years, due to differences in weather conditions and fertilization practices. This inherent variability suggests that our hypothesis can be tested only rigorously when using long-term data sets.

2. Materials and methods

2.1 Site description

Dairy farming is the main agricultural sector in the Netherlands. We considered the Netherlands as a whole, and three contrasting dairy farming regions, (i) Groene Hart (peaty marine clay), (ii) Rivierenland (riverine clay) and (iii) Achterhoek (sand) (Figure 1, and Table 1). Groene Hart with 90% permanent grassland and 6% fodder crops (CBS, 2012) is situated in the west between the main cities Amsterdam, Rotterdam, The Hague and Utrecht. Main soil types are peaty marine clay and peat on marine clay. Rivierenland is situated in the centre of the country between the rivers Rhine, Meuse, and Waal. Seventy five per cent of the agricultural area is grassland, 11% is for fodder crops. Achterhoek is situated in the east. Sandy soils are dominating here, with on average 5.5% soil organic matter (SOM) in the top soil. Of the agricultural area, 66% is grassland and 21% are fodder crops; ley farming (grassland – maize) is rather common.

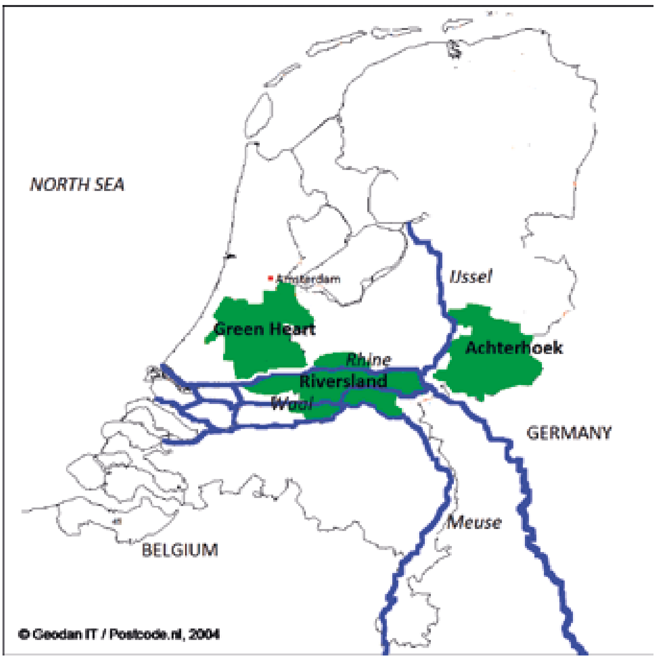


Figure 1. The locations of the studied regions Groene Hart (Green Heart), Rivierenland (Riversland), and Achterhoek.

Table 1 General characteristics of the study regions and the Netherlands (CBS, 2012).

	Regions			The Netherlands
General characteristics (2010)	Groene Hart	Rivierenland	Achterhoek	
Studied/main soil type	Peaty marine clay	Riverine clay	Sandy soil	Mineral soils
Area (ha)	53,100	59,600	105,300	2,074,800
Agricultural area (ha)	49,600 (100%)	56,500 (100%)	99,500 (100%)	1,914,200 (100%)
Grassland (ha)	44,200 (89%)	42,300 (75%)	65,400 (66%)	1,016,400 (53%)
Silage maize (ha)	3,100 (6%)	6,300 (11%)	21,300 (21%)	227,800 (12%)

2.2 Database of soil, herbage, and manure analyses

BLGG AgroXpertus (www.BLGG.AgroXpertus.nl) is the main soil and crop analysis laboratory in the Netherlands. Soil, herbage, and manure samples are taken at farmers' request from 1928 onwards (by more than 50% of the dairy farms). Results of the analyses have been stored in Microsoft Access from 1984 onwards. Before 1984, overviews of soil fertility characteristics were made occasionally (see also Reijneveld et al., 2009, 2010a).

To gain insight in the relationships between soil fertility characteristics and the nutrient element contents of herbage and manure, we choose to analyse the maximum possible period of a certain characteristic.

In herbage, dry matter (DM), crude protein (CP), crude fiber, and crude ash contents are determined from 1960 onwards (based on NEN-ISO 12099). From 1996, phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), calcium (Ca), sulphur (S), and selenium (Se) are digested in nitric acid solution (HNO_3^-), and the macro nutrients are subsequently analysed with Inductivity Coupled Plasma (ICP), while Se is analysed with Inductivity Coupled Plasma – Massa Spectrometry (ICP-MS) (based on NEN 6966; ISO 17294-2).

Regarding manure, only analyses were taken into account that had been voluntarily requested by the farmer; analyses that were legally enforced were excluded from this study. We only considered dairy cattle slurries. Dry matter and crude ash in manure have been analysed gravimetrically after drying – heating, conform NEN-EN 12879 and 12880. Total N was analysed using the Kjeldahl method (NEN 7430; 7433; 7434). P, K, Mg, and Na were determined by Inductively Coupled Plasma spectrometry (ICP), after digestion with sulphuric acid. Total Ammonical Nitrogen (TAN) was measured spectrophotometrically at 660 nm by using a discrete analysis (DA) system (NEN 6604).

2.3 Data selection: farm-level

We selected results of soil, herbage, and manure analyses of farms that were typified as dairy farms on mineral soils. Soils with >25% SOM were considered peat (Anonymous, 2012) and were excluded. To study relationships between soil fertility and herbage quality at the farm level, we averaged the soil test data of 4 years per farm (2005/2006 – 2008/2009) because farmers mostly request for soil tests once in four years, but also to exclude year effects (temperature, precipitation, data of first mowing cut). Results of herbage quality were also averaged per farm over similar 4 years periods (2006 – 2009). Only grass silage results with mowing dates in April and May were selected (spring forage). We selected only farms from the database with at least 4 soil samples and at least 4 grass silage results in a given period. We then combined the soil and herbage data and ended up with 3342 farms in the Netherlands, of which 34, 180 and 335 farms in Groene Hart, Rivierenland, and Achterhoek respectively. We then made correlation matrices between soil characteristics and herbage quality characteristics. Simple and multiple regression analysis was applied to study the relation between soil fertility characteristics and spring herbage quality using the R-command lm (R Core Team, 2013). More complex regression models were chosen only if they performed significantly better by comparing the regression results using the R-command Anova, aiming to gain insight in relationships between soil and herbage quality.

2.4 Data selection: regional level

To study regional effects, 230, 2463 and 568 dairy farms were selected from Groene Hart, Rivierenland, and Achterhoek, respectively, for the period 1996 - 2009. Farms with reports on more than one soil type were excluded. Since soil sampling depth for grassland altered in 2000 and several soil analysis methods changed in 2004 we considered the soil fertility data separately for the periods until 2000, and from 2004 - 2009.

For composition of herbage, summaries and frequency distributions were made. Although herbage data is stored from 1984 onwards, most characteristics are relatively new and therefore only characteristics from 1996 onwards are presented. Manure analyses are not requested as frequently by farmers as soil and herbage analyses. We could therefore not make overviews of manure composition per region but only for the Netherlands as a whole. Results of soil analyses, herbage and manure analysis were analysed statistically (linear regression analysis, Pearson's correlation, t-test), using statistical software of R (R Core Team, 2013) and Microsoft Excel.

Table 2 *Median values, agronomical optimal ranges, and mean annual changes over time (indicated by Slope b) with Spearman correlations (R2), of soil fertility characteristics for the Netherlands and the three regions during the indicated period.*

Region	Characteristics	Unit	Median (2000)	Optimal range	Slope b (SE)	R^2	Period
Netherlands	P-Al	mg P_2O_5 100 g^{-1}	42	~25 – 40	n.s	n.s.	1984 - 2000
	K-HCl	mg K_2O 100 g^{-1}	26	-	0.48**	0.51	1984 - 2000
	Na	mg Na_2O 100 g^{-1}	5	5 – 9	n.s.	n.s.	1989 - 2000
	SOM#	%	7.7	-	n.s.	n.s.	1984 - 2000
	pH-KCl	-	5.4	4.8 – 5.5	n.s.	n.s.	1984 - 2000
Groene Hart	P-Al	mg P_2O_5 100 g^{-1}	43	30 – 40	n.s.	n.s.	1971 - 2000
	K-HCl	mg K_2O 100 g^{-1}	40	-	n.s.	n.s.	1984 - 2000
	Na	mg Na_2O 100 g^{-1}	11	5 – 7	-0.28*	0.42	1989 - 2000
	SOM#	%	16.5	-	-0.04*	0.20	1970 - 2000
	pH-KCl	-	5.6	4.8 – 5.5	n.s.	n.s.	1973 - 2000
Rivierenland	P-Al	mg P_2O_5 100 g^{-1}	33	25 – 35	n.s.	n.s.	1971 - 2000
	K-HCl	mg K_2O 100 g^{-1}	31	-	0.52*	0.38	1984 - 2000
	Na	mg Na_2O 100 g^{-1}	11	5 – 7	-0.22*	0.42	1989 - 2000
	SOM#	%	10.8	-	0.04*	0.16	1970 - 2000
	pH-KCl	-	5.6	4.8 – 5.5	-0.004*	0.17	1973 - 2000
Achterhoek	P-Al	mg P_2O_5 100 g^{-1}	49	30 – 40	n.s.	n.s.	1971 - 2000
	K-HCl	mg K_2O 100 g^{-1}	24	-	0.45**	0.50	1984 - 2000
	Mg-NaCl^	mg MgO 100 g^{-1}	321	151 – 250	7.84***	0.94	1976 - 2000
	Na	mg Na_2O 100 g^{-1}	4	5 – 9	n.s.	n.s.	1976 - 2000
	SOM#	%	6.3	-	n.s	n.s.	1970 - 2000
	pH-KCl	-	5.5	4.8 – 5.5	0.013**	0.62	1977 - 2000

areas with SOM > 25% were excluded from this analysis

^ Mg-NaCl2 was only analysed and recommended on sandy soils

* $p < 0.05$, ** $p < 0.01$, and *** $p<0.001$

n.s. = not significant

3 Results

3.1 Soil fertility characteristics

For the Netherlands as a whole, mean SOM remained constant in the period 1984 – 2000, but for the three regions SOM dynamics varied (Table 2). In Groene Hart (peaty marine clay), SOM decreased significantly ($p<0.05$; on average 1.2%-point in the period 1970 – 2000), while in Rivierenland (riverine clay) a similar increase ($p<0.05$) was observed and no change occurred in the Achterhoek (sandy soil). In the period 2000 – 2009, no significant changes in SOM were found (data not presented).

Median P-Al status was within or above the agronomical optimal range and showed no change over time (Table 2). K-HCl showed a significant increase in all regions except for Groene Hart (Table 2). Soil pH-KCl was within or just above the optimal agronomical range. There was a significant decrease in Rivierenland ($p<0.05$) and a similar increase in Achterhoek ($p<0.01$) (Table 2). The significant increase in soil Mg content in Achterhoek from 'rather low' to 'high' ($p<0.001$) (Table 2 and Figure 2) is in line with the soil-pH increase, and reflects the use of Mg containing lime to raise both soil pH, effective CEC, and Mg content (e.g., Edmeades, 2004). Differences between regions in mean soil fertility characteristics were large, with median SOM, CEC, N-total, S-total, and plant available K, Mg, and Na all decreasing in the order Groene Hart > Rivierenland > Achterhoek (Figure 3).

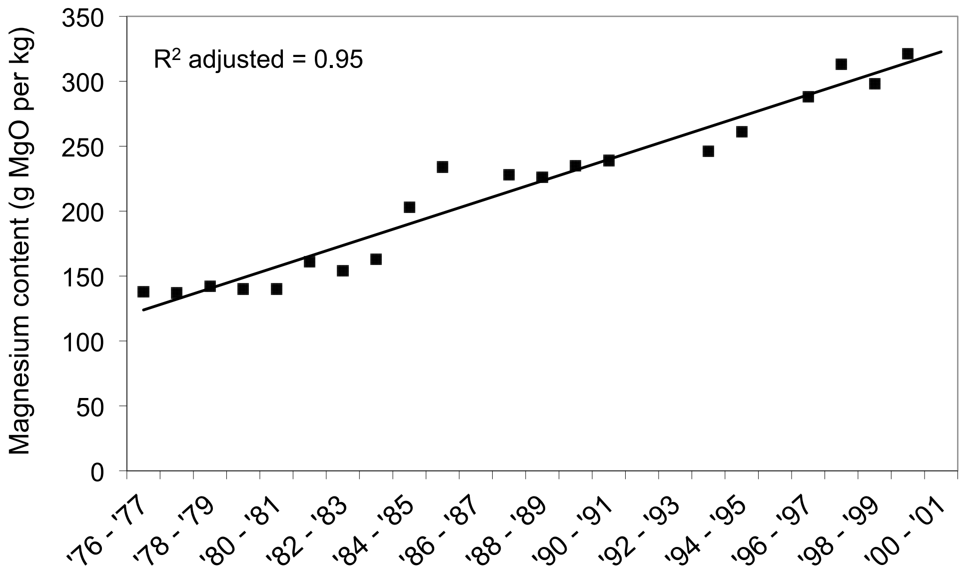


Figure 2. Changes in median soil magnesium content of grassland (period 1976 – 2000) on sandy soils in Achterhoek.

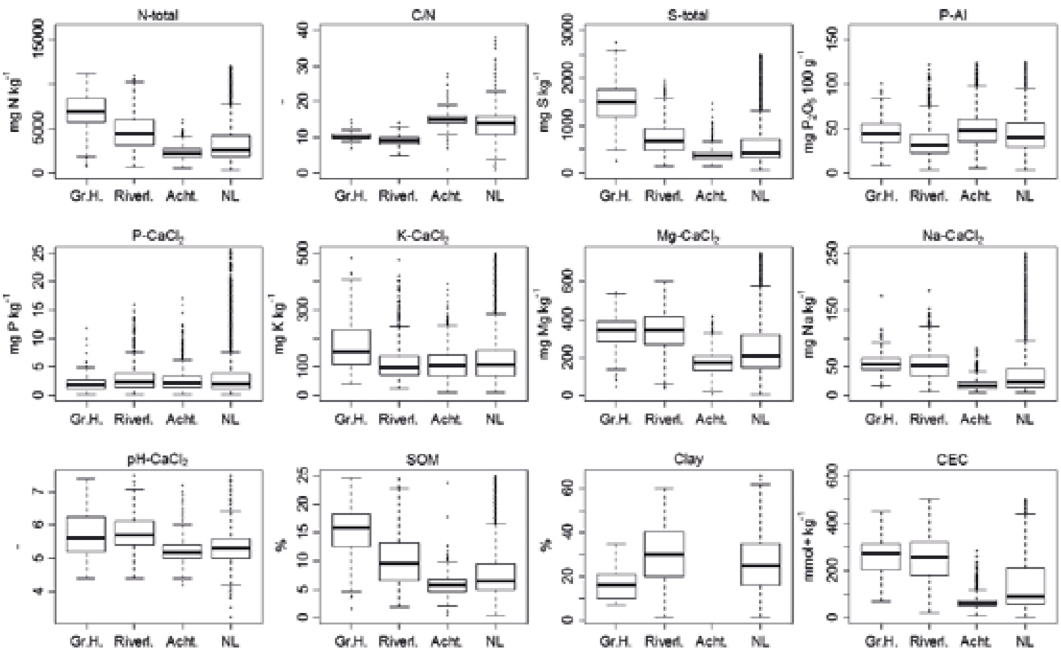


Figure 3. *Boxplots of soil characteristics in the Netherlands, Groene Hart, Rivierenland and Achterhoek.*

3.2. Herbage quality

To exclude possible dilution in herbage quality by increasing DM yields, we obtained a general idea of the cutting age and quality of grasses by considering Acid Detergent Lignin (ADL), and Neutral Detergent Fibre (NDF; cell membrane digestibility). Higher ADL values indicate a later mowing moment (and could therefore explain lower P contents in grass). NDF is an indirect indicator of grass quality. Average ADL values (g kg DM^{-1}) in 2009 ranged between 16.7 (± 2.89) and 20.1 (± 3.34) in Achterhoek and Groene Hart respectively. NDF was lowest in Groene Hart (72% ± 4.07) and highest in Achterhoek (76% ±3.50). So, differences were relatively small and not significant.

Crude protein (CP) of spring silage was highest in Achterhoek (Table 3; Figure 4). The same holds for Mg and Na contents, but not for the Ca content. From 1996 - 2009, more than 65% of the samples had a Ca content below the agronomical range in Achterhoek; which is likely related to the rather low CEC and a low soil pH characteristic for these sandy soils. Median P content was 4 g kg^{-1} and was similar for all regions. Crude protein and crude ash contents clearly decreased during the last 10 years, reflecting reduced N fertilizer use

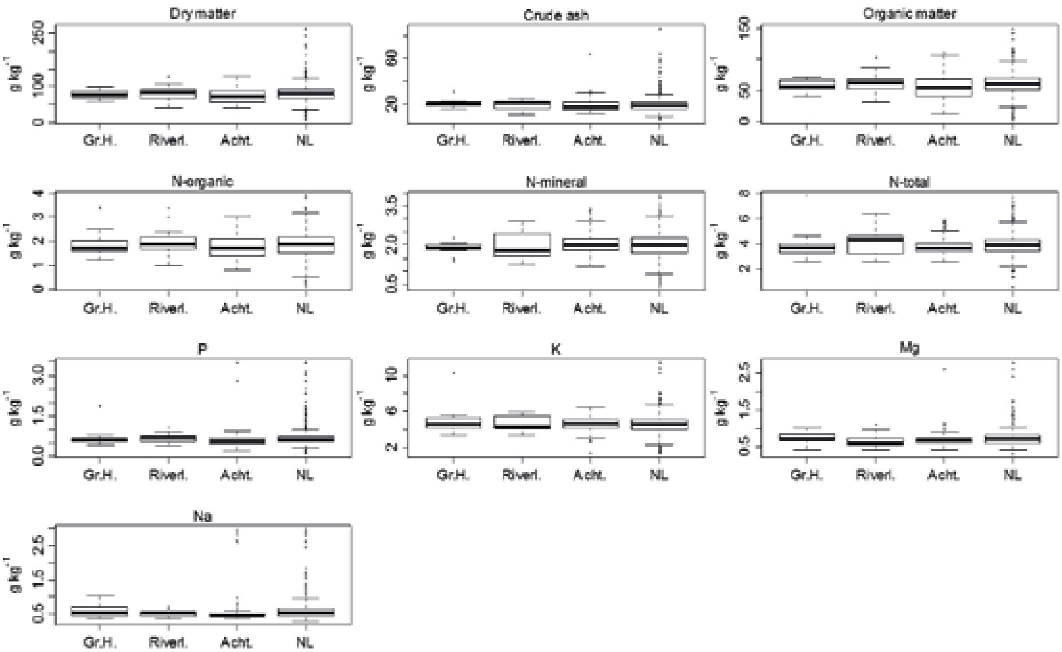


Figure 4. Boxplots of spring forage characteristics in the Netherlands, the Groene Hart Rivierenland, and Achterhoek.

and reduced contamination by soil adherence, respectively (Table 3; Figure 5). Decreased crude protein level in dairy cattle diets can negatively influence milk production and should be monitored (e.g. Frank & Swensson, 2002). No trends in P contents were observed during the period 1996 – 2009 (Table 3). In Achterhoek, K content decreased and S content increased (Figure 5), while changes in other regions were insignificant. The content of Se increased, except for Groene Hart (Table 3; Figure 5e).

3.3 Manure composition

For the Netherlands as a whole, total ammoniacal nitrogen (TAN) content of cattle slurry decreased significantly ($p<0.001$) from 2.36 g kg^{-1} in 1997 to 1.90 g kg^{-1} in 2009. Also N-total and K contents decreased significantly ($p<0.01$) (data not presented). The other elements remained on average rather constant throughout the years, in spite of the large differences between the individual records (Figure 6). The differences between the regions were rather small (Figure 6). Selenium was not measured in manure.

Table 3 *Median values and mean annual change (indicated by Slope b) of herbage quality characteristics in the Netherlands and 3 study regions (Groene Hart, Rivierenland and Achterhoek). The regression coefficient indicates the mean change of herbage quality per year for the period 1996 – 2009.*

Herbage Characteristics[&]	Optimal range	The Netherlands (n ≈ 10.500)			Groene Hart (n ≈ 80)			Rivierenland (n ≈ 440)			Achterhoek (n ≈ 825)		
		Median	Slope b	R^2	Median	Slope b	R^2	Median	Slope b	R^2	Median	Slope b	R^2
Dry Matter	300 - 500	435	n.s	n.s.	394	n.s	n.s.	435	n.s	n.s.	469	n.s	n.s.
Crude Protein	<190	165	-2.43**	0.52	161	-1.63*	0.29	164	-2.72*	0.32	181	-2.71**	0.41
Crude Fiber	230 - 260	242	n.s	n.s.	245	n.s	n.s.	241	n.s	n.s.	232	n.s	n.s.
Crude Ash	-	101	-2.53**	0.69	108	-1.48**	0.59	100	-1.69**	0.60	96	-2.85***	0.74
S	>2	3.0	n.s	n.s.	3.4	n.s	n.s.	2.8	n.s	n.s.	3.2	0.04**	0.46
P	3 - 4.5	4.0	n.s	n.s.	4.1	n.s	n.s.	4.0	n.s	n.s.	4.0	n.s	n.s.
K	25 - 40	35	-0.30*	0.32	38	n.s	n.s.	36	n.s	n.s.	35	-0.43**	0.58
Mg	>2	2.4	n.s	n.s.	2.1	n.s	n.s.	2.1	n.s	n.s.	2.5	n.s	n.s.
Ca	4.5 - 5.5	4.7	n.s	n.s.	5.3	n.s	n.s.	5.2	n.s	n.s.	4.4	n.s	n.s.
Na	2 - 5	2.5	n.s	n.s.	2.2	n.s	n.s.	2.5	n.s	n.s.	2.8	n.s	n.s.
Se	90 - 250	52	8.33**	0.51	52	n.s	n.s.	58	2.30**	0.52	55	3.29***	0.69

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$

[&] DM in g kg^{-1}, Se in mg kg DM^{-1}, all other in g kg DM^{-1}.

n.s.= not significant

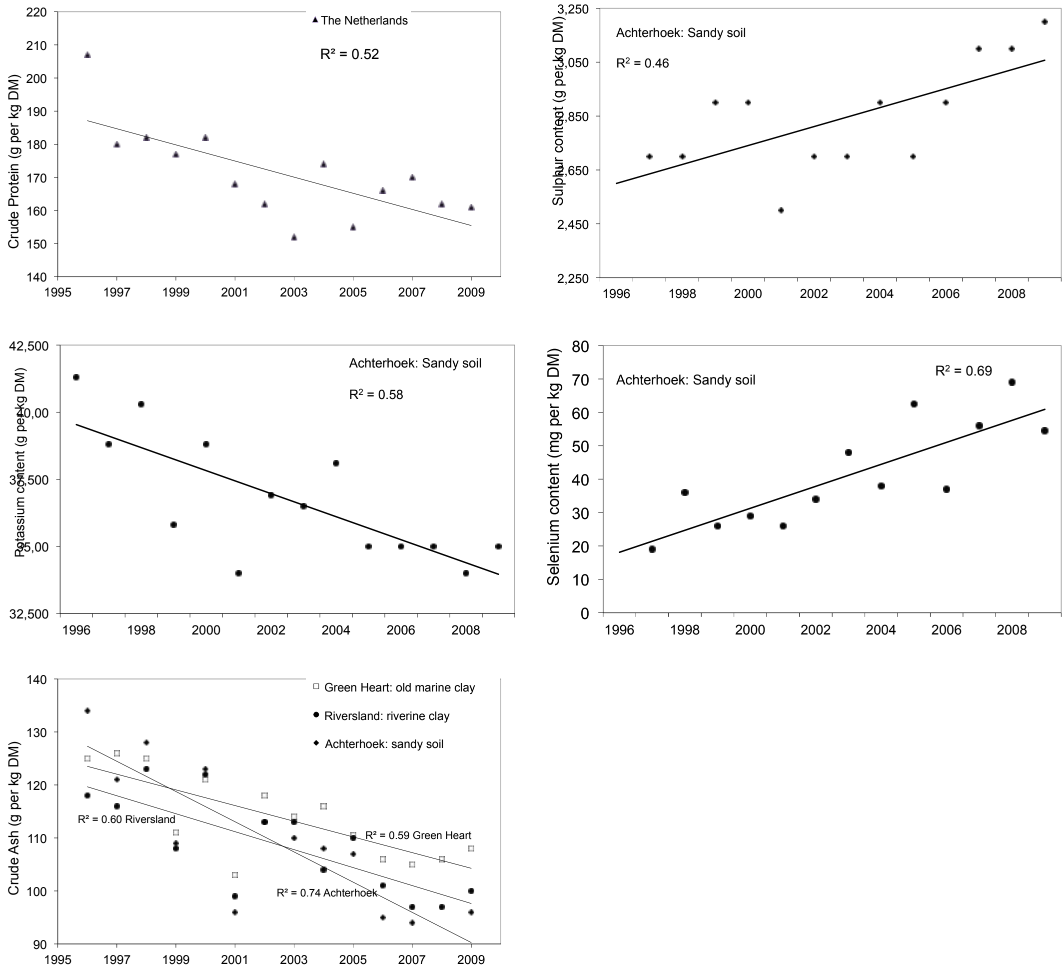


Figure 5. *Changes in grass silage composition in the period ~ mid-1990s until 2009; (a) Crude protein content in the Netherlands; (b) K content in Achterhoek;. (c) S content in Achterhoek; (d) Crude ash content in Groene Hart, Rivierenland and Achterhoek; and (e) Se content in Achterhoek.*

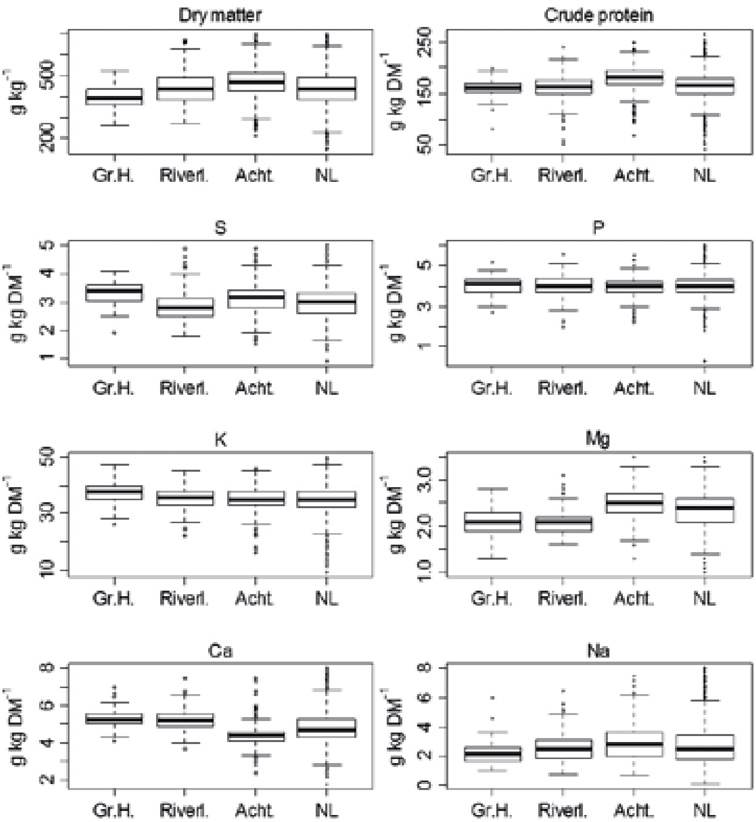


Figure 6. *Boxplots of dairy cattle manure characteristics of the Netherlands, the Groene Hart Rivierenland, and Achterhoek.*

3.4 Relationships between soil fertility characteristics and herbage quality at farm level

Various herbage elements (S, P, K, Mg, Na) could be regressed with the respective soil tests at farm level for the Netherlands as a whole and for the Groene Hart area separately (Table 4). Herbage S was related to the total S content in soil and soil pH. Herbage P was related to P-$CaCl_2$ in Groene Hart, to P-Al in Rivierenland, and to both P-$CaCl_2$ and P-Al in Achterhoek and the Netherlands (Table 4). Herbage K was related to K-$CaCl_2$ in all areas, while herbage Ca was related to soil pH and/or CEC in the Netherlands and Groene Hart, but not in the other areas. Herbage Na was related to soil Na-$CaCl_2$ in Rivierenland; in the other areas herbage Na was negatively related to soil K-$CaCl_2$. For the Netherlands as a whole herbage Na was only related to the soil K-$CaCl_2$/Mg-$CaCl_2$ ratio. Herbage crude protein, crude ash, crude fibre and Se were not related to available soil characteristics.

Table 4 *Significant on farm-level linear correlations between soil fertility characteristics and spring herbage quality in the Netherlands and 3 study regions (Groene Hart, Rivierenland and Achterhoek). Mutliple regressions are shown only if they improve performance significantly.*

Herbage characteristics	The Netherlands Soil characteristics	Correlation R	Groene Hart Soil characteristic	Correlation R	Rivierenland Soil characteristics	Correlation R	Achterhoek Soil characteristic	Correlation R
Dry Matter	-	-	CEC	0.43*	-	-	-	-
Crude Protein	-	-	-	-	-	-	-	-
Crude Fibre	-	-	-	-	-	-	-	-
Crude Ash	-	-	-	-	-	-	-	-
S	S-total#	0.41***	S-total#	0.59***	-	-	-	-
			pH	-0.74***				
			$Mg\text{-}CaCl_2$	0.40*				
			S-tot#+pH+ $Mg\text{-}CaCl_2$	0.80***				
P	P-Al	0.51***	$P\text{-}CaCl_2$	0.41*	P-Al	0.45**	$P\text{-}CaCl_2$	0.49***
	$P\text{-}CaCl_2$	0.41***					P-Al	0.55***
	P-Al+$P\text{-}CaCl_2$	0.62***					P-Al+$P\text{-}CaCl_2$	0.57***
K	$K\text{-}CaCl_2$	0.50***	$K\text{-}CaCl_2$	0.57***	$K\text{-}CaCl_2$	0.44**	$K\text{-}CaCl_2$	0.57***
	$K\text{-}CaCl_2/Mg\text{-}CaCl_2$	0.49***	CEC	0.42*				
	$K\text{-}CaCl_2$ + CEC	0.55***						
Ca	pH	0.53***	pH	0.43*	-	-	-	-
	CEC	0.49***						
	pH + CEC	0.67***						
Mg	pH	-0.62***	pH	-0.70***	-	-	$K\text{-}CaCl_2$	-0.40***
	$Mg\text{-}CaCl_2$	0.40***	$Mg\text{-}CaCl_2$	0.43*				
	CEC	-0.47***	pH+$Mg\text{-}CaCl_2$	0.70***				
	pH + $Mg\text{-}CaCl_2$ + CEC	0.70***						
Na	$K\text{-}CaCl_2/Mg\text{-}CaCl_2$	-0.42***	$K\text{-}CaCl_2$	-0.56**	$K\text{-}CaCl_2$	-0.50**	$K\text{-}CaCl_2$	-0.44***
			CEC	-0.50*	$Na\text{-}CaCl_2$	0.50**		
			$K\text{-}CaCl_2$+CEC	0.56***	CEC	-0.40*		
					$K\text{-}CaCl_2$+$Na\text{-}CaCl_2$+ CEC	0.64***		

 # S-total and SOM are highly correlated and are interchangeable here. ** $p < 0.05$, ** $p < 0.01$, and *** $p<0.001$*

4. Discussion

4.1 Relationships on practical farms

To our knowledge there are very few reports on relationships between soil fertility and herbage and manure composition on dairy farms at regional levels or at farm level. So far, studies mainly focused either on soil fertility characteristics (e.g., Reijneveld et al., 2009; 2010a; 2012a; Wheeler 2004; Ketterings et al., 2005), herbage quality (e.g., Cop et al., 2009; Hemingway, 1999) or manure composition (e.g. Van Kessel & Reeves, 2002) studied separately. Relationships between soil fertility and herbage quality and manure composition have been evaluated only on the basis of field experiments (e.g., Jarvis & Whitehead, 1981; Soder & Stout, 2003; Klapwijk & Ketterings, 2006; Mahli et al., 2010) and animal nutrition experiments (e.g., Grunes and Welch, 1989; Mayland and Wilkinson, 1989). Such relationships are often rather complex because of the interactions with soil chemical, physical and biological processes, variable weather conditions, plant and animal traits and physiological status, and management. As a consequence, generalizing results from experiments can be problematic. On the other hand, in our study all these influential factors are included, doubtless resulting in large variation. Therefore we considered a very large data set. To our knowledge for the first time, we studied the relationship between soil fertility and herbage and manure composition with a large data set of practical farms.

4.2 Relationships between herbage quality and soil fertility at farm level

At farm level soil fertility characteristics were clearly correlated with herbage quality (Table 4). These relations were found without information about farming practices such as fertilization, yield, and irrigation. Also, we assumed that the soil fertility characteristics of the fields sampled were representative for the fields harvested. Most dairy farms have about 10 fields, but not all fields are sampled for soil fertility evaluation. We included dairy farms in our sample population when the number of fields analysed was at least 4. The significant correlation between soil fertility characteristics and herbage quality suggests that the between-farm variation was larger than the within-farm variation. For example, a significant correlation between soil and herbage P (Table 4) was found. This is comparable to results from Schulte & Herlily (2007) and Grunes &Welch (1989) who also reported soil P to be correlated with herbage P contents.

In the near future more detailed data will become available, as GPS positions of the origin of soil and herbage samples are registered, and yields of harvested grass and maize are recorded per field. This may result in more precise insight into the actual relations between local soil fertility, farm management (among others fertilization), and herbage quality and yield. As a result, farmers may be given more customized recommendations to improve or maintain soil the soil fertility status.

4.3 Changes of soil fertility indices over time

Soil fertility status and herbage quality on dairy farms appeared to be within or slightly above optimal agronomical ranges (Table 3) . Decades of high nutrient surpluses on dairy farms in the Netherlands (e.g., Van Keulen et al., 1996; Smaling et al, 1999; Boers & Noij, 1997, CBS 2012; Csathó & Radimszky, 2009) has contributed to the accumulation of especially immobile elements in soil (e.g., P), but apparently did not yet result in excessive high values in herbage.

SOM of grasslands and land used for silage maize remained rather stable (Table 2) as has been reported also by Hanegraaf et al. (2009), and Reijneveld et al. (2009). The soil P status also remained stable and within or just above the optimal agronomical range during the last 4 decades (Table 2; see also Reijneveld et al., 2010a), despite large positive P balances during the last decades (e.g., Bindrabin et al., 2000; CBS 2012) The positive K balances did however reflect in an increased soil K status. Although it is known that an increasing K status can cause a decline of soil Mg status (e.g. Morton et al., 2004), a significant increase in soil Mg was observed for the Achterhoek (Figure 2). This latter increase was likely caused by the increased application of Mg-containing fertilizers and lime (Anonymous, 1998).

From 2000 – 2010 (data not given), no significant changes in soil characteristics (including SOM, P-Al, pH-KCl, and P-, K-, Mg-, and Na-$CaCl_2$) were found, suggesting limitations in manure (and N, and P artificial fertilizers) application rates have not yet have affected soil fertility.

4.4 Differences between regions in herbage quality and soil fertility

The soil fertility characteristics SOM, N-total, S-total, Na-$CaCl_2$, Mg-$CaCl_2$ and CEC in soil were on average 2 – 4 times higher on the peaty marine clay soils of Groene Hart compared to the sandy soils of Achterhoek. These mean regional differences in soil fertility indices were not reflected in significant differences in mean herbage quality between regions (Figure 4). In contrast, crude protein, and Na and Mg contents increased in more or less reversed order (Groene Hart ≤ Rivierenland < Achterhoek; Figure 4). Also, S-total was 4 times higher in Groene Hart compared to Achterhoek (Figure 3); yet, comparable herbage S contents were found in the herbage (Table 3; Figure 4). Herbage S content in Achterhoek had significantly increased by S fertilization, which has been promoted from the beginning of the 2000s to improve grass quality and yield (Scherer, 2001; Gierus et al., 2005; Anonymous, 2002). Similarly, Se fertilization was promoted on sandy soils from the 2000s and this increased Se content in herbage significantly (Table 3; Figure 5e) (Ouweltjes & Schils, 2002). Evidently, fertilization practices greatly influence the relationships between soil fertility indices and herbage quality.

The Ca content of grass silage was higher on peaty marine clay and riverine clay than on the sandy soils. This may be explained by the higher CEC and exchangeable Ca on the clayey soils compared to the sandy soils. Soil pH ranged between 5 and 6 in all three regions. The relatively low Ca content of herbage in the Achterhoek (65% of the samples was below the optimal range for dairy cows) may predispose animals to milk fever if K nutrition is high (Goff et al., 1997; Soder and Stout, 2003). However, K intake by dairy cows is modest here, because of the high share of relatively low-K silage maize in the ration of dairy cows.

4.5 Manure composition

Animal manure is wordlwide a valuable resource of organic carbon and nutrients, also on grassland-based dairy farms, but the composition is usually highly variable and, as a result of that, poorly known. The composition of manures collected in farming systems reflects the animal type and its performance, the animal diet, the addition of litter and (spilling) water, storage conditions and duration, and gaseous losses (Powers & Van Horn, 2001). On average 10 to 40% of the nutrients in the animal diet ends up in milk and beef, while the remaining 60 to 90% of the nutrients in the animal diet ends up in manure (e.g., Suttle, 2010). These nutrients in manure can be recycled on the farm, but the utilization is often rather low because of the variable and unknown composition and the difficulties with appropriate application and timing, resulting in losses by leaching and runoff.

During the period 1997 – 2010, N-total, TAN, and K contents in dairy cattle manure significantly decreased, which likely is a reflection of decreasing N and K fertilizer inputs during this period (CBS, 2012). In contrast, P and Mg contents in manure remained stable. Differences between regions in the composition of dairy cattle slurries were small. The mean P content of dairy cattle slurry in the Netherlands was 1.50 g kg^{-1}. The mean P content in the Achterhoek (1.34 g kg^{-1}) was slightly lower (Figure 6), which may reflect the larger share of low-P silage maize in the diet.

5 Conclusions

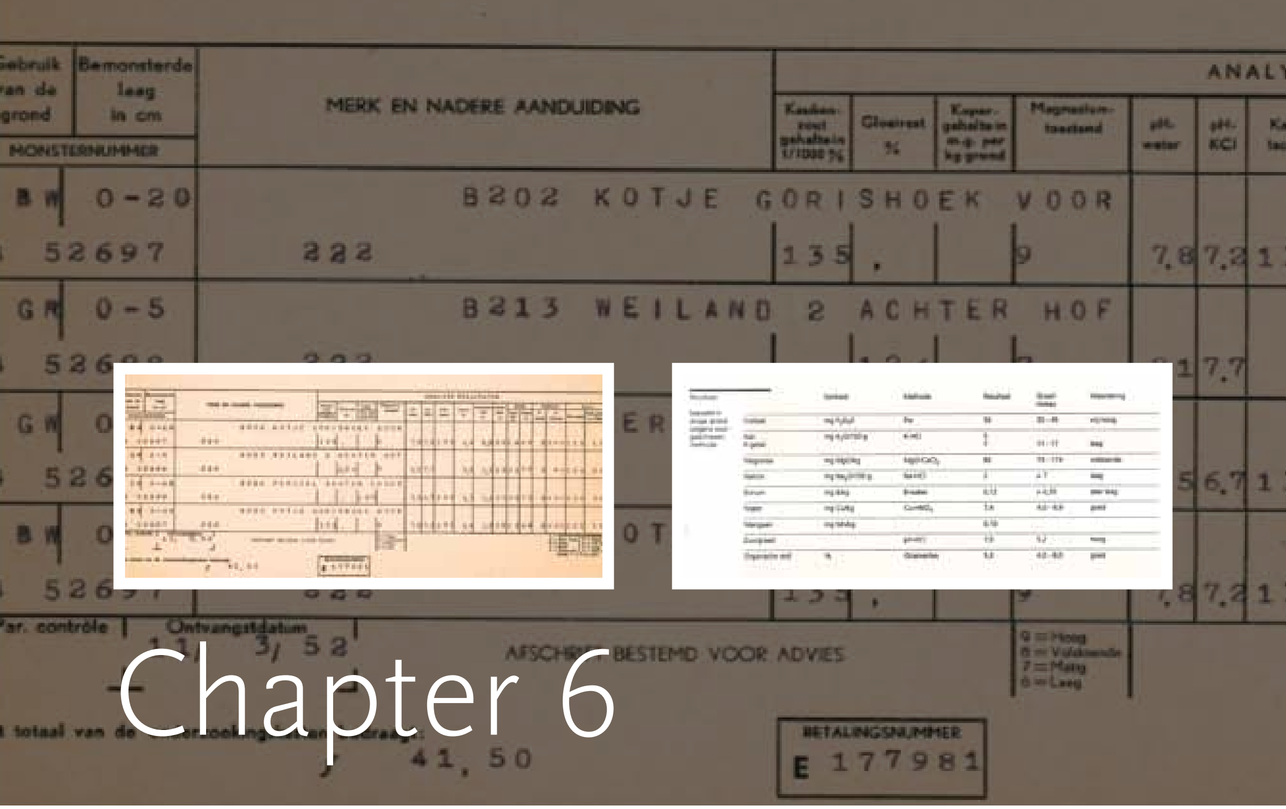
The main soil fertility and herbage quality characteristics were within or just above the optimal agronomical levels, in all three study regions as well as for the Netherlands as a whole.

Changes in soil fertility characteristics were relatively small during the last decades. Changes in the composition of herbage for some characteristics (e.g., crude protein, crude ash, Se, S) reflect changes in fertilization and farming practices, which were incentivised in part by governmental regulations (e.g., N and P application limits), extension services (Se and S fertilization) and technological developments (changes in silage making).

At farm level, the element composition of herbage reflected the soil fertility status. The contents of S, P, K, Na, Mg, and Ca in the herbage were all significantly influenced by soil fertility characteristics.

Differences between regions in average soil fertility characteristics were not reflected in equal differences in herbage and manure composition. The contents of crude protein, Mg and Na in herbage increased in the order Groene Hart < Rivierenland < Achterhoek, while soil fertility would have suggested otherwise. Dairy farms on sandy soils were able to obtain a rather similar quality of herbage compared to dairy farms on clay soils. The lower fertility on sandy soils was in part compensated by increased usage of fertilizer (S, Mg, Se) and lime (Ca, Mg).

Relationships between soil fertility indices and herbage quality and manure composition may become more precise when linkages can be made at field level between soil and herbage (and manure) characteristics. This opens the scope for more precise recommendations in near future.



Chapter 6

A STRATEGY FOR INNOVATION IN SOIL TESTS ILLUSTRATED FOR PHOSPHORUS TESTS

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Abstract:

Soil phosphorus (P) tests are used for P fertilization recommendations, environmental evaluations and occasionally for legislation purposes. The basis of fertilization recommendation as function of soil P status was established mostly in the 1950s - 1960s. Since then the agro-economic environment has altered: environmental protection became increasingly important and P rock resources for fertilizers appeared exhaustible. Also, new insights in soil testing and fertilization recommendations reflecting more efficient use of P became available. However, these new insights seem hard to implement into agricultural practice, to a large extent because replacing existing soil tests and recommendations would imply a very significant effort with respect to introducing new tests and recommendations by fertilisation trials in practice. The same would apply for environmental evaluations.

Here, we propose a novel, three-step schedule for introducing new soil tests: (1) establishing new promising soil tests, (2) creating regression models between the old and new soil tests, and (3) implementing the new soil test stepwise by fertilisation trials. In this way, the knowledge based on the old soil tests can be used until the new soil tests and their subsequent crop responses are validated sufficiently.

As novel P-test we considered combining soil P intensity (as reflected by P-$CaCl_2$) with P-capacity (as reflected by P-Al), and P-buffering capacity (as reflected by P-Al/P-$CaCl_2$ ratio) characteristics. We tested whether this novel soil test can predict Pw, P-CAL, and P-Olsen values. To test our hypothesis we used 4 datasets (2 with Pw, 1 with P-CAL, and 1 with P-Olsen). In all datasets additional soil characteristics were available including soil type. Regression models with R_{adj}^2 from 0.80 - 0.93 were obtained by using P-Al, P-$CaCl_2$, and soil type. We conclude that these regressions can be used as a helpful intermediate instrument when introducing fertilization recommendations based on new soil tests. Predicting one soil P test out of other soil characteristics, analogous to the predicted Pw, P-CAL, and P-Olsen, could also be helpful in comparing P statuses of agricultural land in different nations.

Keywords:

Phosphorus, soil test, Pw, P-Al, P-$CaCl_2$, P-Olsen, P-CAL, database, fertilization recommendation

Introduction

An adequate soil phosphorus (P) status guaranteeing an adequate P supply to growing crops is crucial for optimal crop production. Most countries in the world have established P fertilisation recommendations as function of soil P test values, soil type and crop type. Many countries also have recommendations for optimal soil P test values.

A universal soil P test does not exist, and there is consequently no universal fertilisation recommendation. Only in Europe dozens of soil P tests have been developed (Alva, 1993; Tunney et al., 1997), for details, see the soil analyses paragraph below. For example, P-Al (Egnér et al., 1960) is used in Belgium, Estonia, Hungary, Norway, Romania, Sweden, and The Netherlands; P-CAL (Schüller, 1969) in Germany and Austria; P-water (Pw) (Sissingh, 1971; Van der Paauw, 1971) only in the Netherlands, and P-Olsen (Olsen et al., 1954) in Denmark, Greece, Italy, Poland, Spain, and the United Kingdom. P-Olsen is also used in e.g. New Zealand, and the United States. Mehlich 3 (Mehlich, 1984) and P-Bray I (Bray & Kurtz, 1945) are also commonly used (Sims et al., 2002). In many countries several soil P methods are in use, aiming at different cropping systems (e.g. arable land, grassland, glasshouse crops, environmental research). For example, in the Netherlands P-Al is used for grassland (Anonymous, 2002), Pw for arable farming and horticulture (Anonymous 1999), and P-Al in combination with P-$CaCl_2$ (0.01 M $CaCl_2$, dried soil) is used for maize land (Anonymous, 2011).

Relations between soil P test values, P fertilization and crop responses have been established through numerous pot experiments and field trials (Voss, 1998). Just for one method, often many studies have been carried out. For example, the basis of the P recommendation as function of soil Pw, crop and soil types in The Netherlands have been described by many authors (e.g. Van der Paauw et al., 1971; Bakker, 1968; 1971; Ris and Van Luit, 1973; Prummel, 1979; 1981; Ris, 1972). Soil P tests are increasingly used also in environmental research as predictor for P leaching (Anonymous, 2009; Schoumans and Groenendijk, 2000; Koopmans et al., 2001, 2004b; Pautler and Sims, 2000; Beauchemin and Simard, 1999).

The basis of fertilization recommendations as function of soil P status was established mostly in the 1950s - 1960s (Voss, 1998). Since then, the agro-economic environment has altered, environmental protection became a topic (e.g. Csathó et al., 2007, Neeteson et al., 2001), laboratory methods have improved (e.g. increased precision and decreased duration and costs of analyses), and P resources proved exhaustible (Heffer et al., 2006; Cordell et al., 2009). New insights for more efficient fertilization recommendations, based on more knowledge of soil P – plant – environment interactions were obtained in the last decades (e.g. Schofield, 1955; Rotterdam-Los., 2010). However, new insights seem hard to implement into agricultural practice, to a large extent because replacing an old by a new soil P test would require a very significant effort with respect to testing and validation of new recommendations by fertilisation trials in practice. The same applies to environmental applications.

Here, we propose a novel approach in three steps for implementing new tests and insights in practice: (1) establish new soil tests (which are more precise, cheaper and faster), (2) prepare regression models predicting the old test data on the basis of the new soil test, and (3) implement the new knowledge and insights stepwise. In this way the knowledge based on the 'old' soil tests and fertilization trials can be used until the new soil tests and their subsequent crop responses are validated sufficiently to completely replace the old test and its recommendations.

In recent research combining soil P intensity characteristics with a P-capacity characteristic, and with an indicator for the P-buffering capacity of the soil is promoted (Moody et al, 1988; Dear et al., 1992; Bolland et al., 1994; Van Rotterdam – Los, 2010). Here we use P-$CaCl_2$ as an intensity indicator, P-Al as a capacity indicator, and the ratio P-Al / P-$CaCl_2$ as an indicator for buffering capacity. We tested if P-$CaCl_2$, P-Al and its ratio (P-Al / P-$CaCl_2$) can predict three different soil tests, namely Pw, P-CAL, and P-Olsen. To test our hypothesis we used four datasets, two datasets with Pw, one with P-CAL, and one with P-Olsen. All datasets contained information about P-$CaCl_2$, P-Al, some selected other characteristics, and soil type. The third step, a step wise introduction of P-$CaCl_2$ and P-Al, is described for maize land.

Materials and methods

Datasets

We used four data sets. Dataset 1 consists of records of 585 soil samples that were taken and analysed in the period 1993 – 1996 to study the prospects of using 0.01 M $CaCl_2$ as extractant for soil analyses (Kusters, 1997; Titulaer, 1998). The soil samples originate from a survey of agricultural fields in The Netherlands (including grassland, arable land and horticultural land) (Table 1). Dataset 2 consists of 3826 records of routine soil tests at farmers' request in the BLGG AgroXpertus database from 2004 to 2009 (Table 2). Although dataset 2 was not designed to obtain a representative overview, still the soil characteristics are very diverse and rather comparable to that of dataset 1 (Table 2). In both datasets, 7 soil types were distinguished (see also Anonymous, 1999; Anonymous, 2002). Dataset 3 has 729 records containing P-CAL, P-Al, P-$CaCl_2$ and other soil characteristics, and originated from a sample of agricultural soils in Germany. Dataset 4 has 170 records with P-Olsen, P-$CaCl_2$, P-Al and other soil characteristics, and originated from a sample of agricultural soils in Denmark.

Table 1. Summary statistics of the main soil characteristics (all samples, and for sand and marine clay soils) of dataset 1.

Soil characteristic	Pw mg P2O5 l-1	$P\text{-}CaCl_2$ mg P kg^{-1}	P-Al mg P_2O_5 100 g^{-1}	pH	SOM %	Clay %	$CaCO_3$ %
All samples (N = 585)							
Mean	70	6.3	73	6.4	4.3	11	1.9
Median	62	4.6	66	6.7	3.1	9.3	0.2
Minimum	4	0.2	4	3.8	0.1	0	0
Maximum	448	44	461	8.1	35	58	25
Sand (N = 195)							
Mean	87	8.9	85	5.6	3.5	-	-
Median	81	6.8	76	5.6	3.2	-	-
Minimum	5	0.2	8	3.8	1.0	-	-
Maximum	286	44	161	7.5	15.6	-	-
Marine clay (N = 164)							
Mean	56	4.1	69	7.2	4.9	20	4.6
Median	55	3.5	66	7.3	3.9	20	4.3
Minimum	5	0.2	9	5.0	1.1	8.2	0
Maximum	196	21	210	7.8	13.9	42	12.8

Soil analyses

Soil P was determined with Pw, P-CAL, P-Olsen, P-Al, $P\text{-}CaCl_2$. Pw is a 1:60 (v/v) extraction with water (Sissingh, 1971; Van der Paauw, 1971). P-CAL is a 1: 20 (w/v) extraction with 0.05 M calcium lactate + 0.05 M calcium acetate + 0.3 M acetic acid method (pH 4.1, 2h shaking) (Schüller, 1969). P-Olsen is a 1:20 (w/v) extraction with 0.5 M sodium bicarbonate (pH 8.5, 20 minutes stirring), originally developed for calcareous soils. P-Al is an extraction with 0.1 M ammonium lactate and 0.4 M acetic acid at pH 3.75 (Egnér et al., 1960), and $P\text{-}CaCl_2$ an extraction with 0.01M $CaCl_2$ (Houba et al., 1994; 1998; NEN 5704; Van Erp et al., 1998).

Table 2. Summary statistics of the main soil characteristics (all samples, and for sand and marine clay soils) of dataset 2.

Soil characteristics	Pw mg P_2O_5 l^{-1}	P-$CaCl_2$ mg P kg^{-1}	P-Al mg P_2O_5 100 g^{-1}	pH	SOM %	Clay %	$CaCO_3$ %
All samples (N = 3826)							
Mean	43	2.5	41	5.7	6.3	11.4	3.3
Median	37	1.7	38	5.4	3.9	8	3.4
Minimum	4	0.2	3	2.0	0.4	1	0.1
Maximum	369	44.6	238	8.0	63.7	69	11.4
Sand soil (N = 986)							
Mean	42	2.3	46	5.1	4.0	-	-
Median	34	1.5	42	5.2	3.8	-	-
Minimum	4	0.2	3	3.5	0.5	-	-
Maximum	315	44.6	189	6.7	14.6	-	-
Marine clay soil (N = 137)							
Mean	49	2.4	51	7.3	3.3	22	5.7
Median	49	1.9	51	7.4	2.8	21	6.2
Minimum	4	0.2	18	5.8	1.4	8	0.1
Maximum	189	11.	150	7.7	10.9	43	10.1

Soil organic carbon (SOC) was determined as elemental C following dry combustion when SOC was low (Yeomans & Bremner, 1991; Soon & Abboud, 1991). Soils rich in SOM (all soils under grassland) were analysed using loss–on-ignition (NEN 5754, 2005). In all cases, soil organic matter (SOM) was reported to the farmers, calculated as SOC × 2. Inorganic carbonate ($CaCO_3$) was determined via Scheibler method (NEN-ISO 10693; Bruin, 1937). Soil pH was determined in 1 M KCl (NEN-ISO 10390, 2005), and the clay content was determined through density fractionation (Hooghoudt, 1945, NEN 5753, 2006). Soil pH and contents of SOM, $CaCO_3$ and clay were taken into account because of their possible interactions with plant-available P (e.g., Lindsay, 1979; Hinsinger, 2001; Brady and Weil, 1999; Bakker et al., 2005). Pw was determined in duplicate or triplicate because of analytical problems (Henkens, 1984; Bussink et al., 2003).

Data analysis

For all datasets, we performed multiple regressions using function “lm” in R (R Development Core Team, 2010) to predict measured Pw with the selected soil characteristics. We attempted several approaches including log and square root transformations in case of non-normality of data and P-Al/P-$CaCl_2$ ratios. Model simplification was carried out with the "step" function in R.

Since we could use two datasets with Pw, regressions obtained with dataset 1 were validated with dataset 2 and vice versa. We carried out regressions for the separate soil types. Soil types with < 25 soil samples were not taken into account (reclaimed peat, and clayey peat/peat in dataset 1, and sea sand, riverine clay, and loess in data set 2).

Results

Prediction of Pw

Datasets 1 and 2 showed high correlations between Pw and P-$CaCl_2$ ($R_{adj.}^2$ = 0.81 and 0.67, respectively) as well as between Pw and P-Al ($R_{adj.}^2$ = 0.70 and 0.66, respectively). The relationships improved significantly by putting both P-$CaCl_2$ and P-Al in an additive multiple regression model ($R_{adj.}^2$ = 0.85 and 0.81, respectively) (Table 3 and 4). Neither adding the ratio term (P-Al/P-$CaCl_2$) nor the interaction term (P-$CaCl_2$ × P-Al) further improved the models significantly. Likewise, adding other soil characteristics, or carrying out transformations did not improve the models. Still, the residual standard error was rather high (Tables 3 and 4), and we therefore studied the soil types separately.

Table 3. Multiple linear regression relations for Pw for all samples and for specific soil types separately. Analyses made with dataset 1. The last column indicates correlation coefficients between the regressions shown versus the regressions based on dataset 2 (Table 4) .

Dataset 1	Model	N	R^2 adj.	Residual s.e.	R^2 adj. models
Overall	14.56 (±1.49) + 4.910 (±0.21) P-$CaCl_2$ + 0.336 (±0.03) P-Al	585	0.85	19.47	0.99
Soil Type					
Sea sand	9.26 (±2.66) + 5.222 (±0.42) P-$CaCl_2$ + 0.208 (±0.05) P-Al	66	0.91	9.83	-
Sand	22.64 (±2.22) + 4.722 (±0.22) P-$CaCl_2$ + 0.257 (±0.03) P-Al	195	0.90	16.0	0.99
Marine clay	8.75 (±2.03) + 6.429 (±0.41) P-$CaCl_2$ + 0.300 (±0.04) P-Al	164	0.88	10.85	0.87
Riverine clay	14.41 (±3.29) + 4.349 (±0.90) P-$CaCl_2$ + 0.442 (±0.09) P-Al	89	0.81	16.71	-
Loess	6.45 (±5.41) + 29.53 (±3.66) P-$CaCl_2$ – 0.179 (±0.039) P-$CaCl_2$ x P-Al	29	0.89	20.24	-

Table 4. Multiple linear regression relations for Pw for all samples and for specific soil types separately. For marine clay, additional soil parameters were included. Analyses made with dataset 2. The last column indicates correlation coefficients between the regressions shown versus the regressions based on dataset 1 (Table 3) .

Dataset 2	Model	N	R^2 adj.	Residual s.e.	R^2 adj. models
Overall	7.13 (±0.43) + 5.165 (±0.10) P-$CaCl_2$ + 0.596 (±0.01) P-Al	3826	0.81	13.79	0.99
Soil Type					
Sand	3.13 (±0.88) + 6.010 (±0.16) P-$CaCl_2$ + 0.538 (±0.02) P-Al	986	0.84	11.38	0.99
Marine clay	-18.39 (±26.16) + 3.461 (±0.97) P-$CaCl_2$ + 0.810 (±0.10) P-Al + 7.898 (±3.42) pH – 4.903 (±0.63) $CaCO_3$ – 0.385 (±0.13) clay%	137	0.80	7.72	0.77
Reclaimed peat	1.74 (±2.93) + 5.188 (±0.86) P-$CaCl_2$ + 0.652 (±0.07) P-Al	74	0.86	9.99	-
Clayey peat/ peat	0.43 (±0.67) + 5.371 (±0.80) P-$CaCl_2$ + 0.304 (±0.06) P-Al	79	0.91	3.26	-

When for datasets 1 and 2 the soil types were evaluated separately, the Pw was explained by P-$CaCl_2$ and P-Al from $R_{adj.}^2$ = 0.80 (marine clay, dataset 2) up to $R_{adj.}^2$ = 0.91 (sea sand, dataset 1 and clayey peat/peat, dataset 2) (Table 2). Adding the interaction P-$CaCl_2$ × P-Al into the equation on loess (dataset 1) resulted in a significant increase of $R_{adj.}^2$ from 0.80 to 0.89. On marine clay (dataset 2) including pH, $CaCO_3$, and clay content increased the $R_{adj.}^2$ from 0.70 to 0.80, all parameters being highly significant ($p<0.001$). Although not for all soil types the $R_{ajd.}^2$ increased compared to the overall model, the residual standard errors decreased considerably (Table 3; 4).

Validating the regression model based on dataset 1 with dataset 2 resulted in high correlation coefficients for the overall and the sandy soil models (both $R_{adj.}^2$ = 0.99). The models for marine clay showed lower comparable $R_{adj.}^2$ (0.88 and 0.87). The regression model based on dataset 2 ($R_{adj}.^2$ = 0.80) resulted in a slight decrease when fit with dataset 1 ($R_{adj.}^2$ = 0.77). In all cases, the models based on dataset 1 were not significantly different from those of dataset 2, and we therefore combined the datasets (Table 5; Fig. 1). Because of the low number of data for the loess soil type (n=29), we attempted to combine these data with the marine clay model. Although the R^2_{adj}. decreased to 0.80, the standard errors (Figure 2g) decreased too, and therefore the marine clay model was also used for loess.

Table 5. Final multiple linear regression relations for Pw with datasets 1 and 2 combined.

	Model	N	R^2 adj.	Residual s.e.
Overall	10.92 (±0.42) + 4.750 (±0.09) P-$CaCl_2$ + 0.501 (±0.01) P-Al	4411	0.81	15.91
Soil Type				
Sea sand	9.26 (±2.66) + 5.222 (±0.42) P-$CaCl_2$ + 0.208 (±0.05) P-Al	66	0.91	9.83
Sand	0.12 (±1.03) + 5.991 (±0.38) P-$CaCl_2$ + 0.592 (±0.03) P-Al	1151	0.86	7.38
Marine clay and loess	6.88 (±1.88) + 5.612 (±0.416) P-$CaCl_2$ + 0.324 (±0.04) P-Al	298*	0.80	8.44
Riverine clay	14.41 (±3.29) + 4.349 (±0.90) P-$CaCl_2$ + 0.442 (±0.09) P-Al	89	0.81	16.71
Reclaimed peat	1.74 (±2.93) + 5.188 (±0.86) P-$CaCl_2$ + 0.652 (±0.07) P-Al	74	0.86	9.99
Clayey peat/peat	0.43 (±0.67) + 5.371 (±0.80) P-$CaCl_2$ + 0.304 (±0.06) P-Al	79	0.91	3.26

Records with Pw > 150 were left out of the analyses.

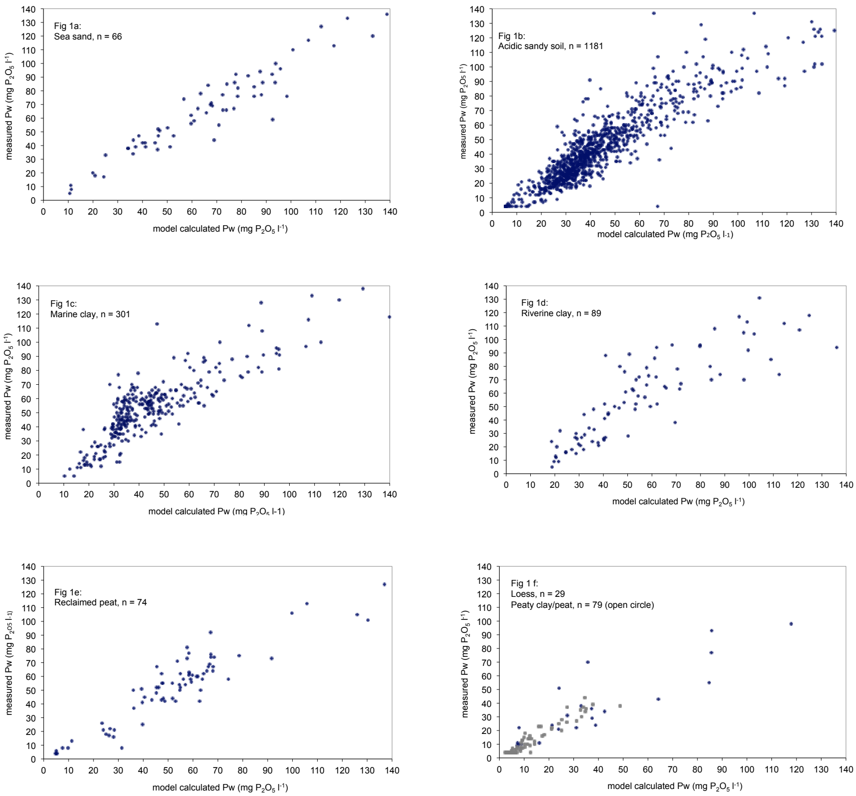


Figure 1 Comparison of predicted (according to Table 5) versus measured Pw.

A calculated Pw should perform well in the agronomical relevant ranges. Recommendations for P fertilization based on Pw distinguish 6 categories, from low (Pw <11) to high (Pw >60) (Anonymous, 1999): the range between 21 – 30 is described as 'sufficient', and 31-45 as 'ample sufficient'. Current Dutch nutrient management policy deviates somewhat from this range, and considers a Pw < 25 as 'poor', the range 25-35 as 'low', 35-55 as 'neutral', and >55 as 'high' (Anonymous, 2009). Either way, the relation between Pw and P-$CaCl_2$ and P-Al must be reliable in the range of roughly Pw 0-75. Values above 75 are of lesser importance, with respect to reliability of prediction. In our datasets, especially in dataset 2, the mean and median values lie well within this range. Regressions were not significantly affected by leaving out records with Pw>75.

Standard error of measured versus *predicted Pw*

One of the most important performance criteria for laboratory procedures is the intra-laboratory reproducibility, here abbreviated ILR. This is determined by producing duplicates from the same samples at different days, different analysts, different instruments and so on (NEN 7777, 2003). The ILR-profile is determined for the complete analytical range, meaning from detection limit to the maximum concentration to be measured. Examples for the IRL-profiles for Pw (solid and dotted lines) are shown in Figure 2.

To compare the IRL-results for both approaches, the IRL-information for P-$CaCl_2$ and P-Al has to be transformed into a "Pw space" similar to the analytical results. This is achieved by calculating for all samples involved the weighted variance in IRL for both methods as follows:

$$IRL'^{2}_{i\ Pw} = ((f_{P\text{-}CaCl_2} \times IRL_{i\ P\text{-}CaCl_2})^2 + (f_{P\text{-}Al} \times IRL_{i\ P\text{-}Al})^2) \quad [1]$$

where:

$IRL'_{i\ Pw}$ = estimated intra-laboratory reproducibility for the predicted Pw from sample i

$f_{P\text{-}CaCl_2}$ = coefficient for P-$CaCl_2$ from the Pw prediction model

$IRL_{i\ P\text{-}CaCl_2}$ = P-$CaCl_2$ result for sample i

$f_{P\text{-}Al}$ = coefficient for P-Al from the Pw prediction model

$IRL_{i\ P\text{-}Al}$ = P-Al result for sample i

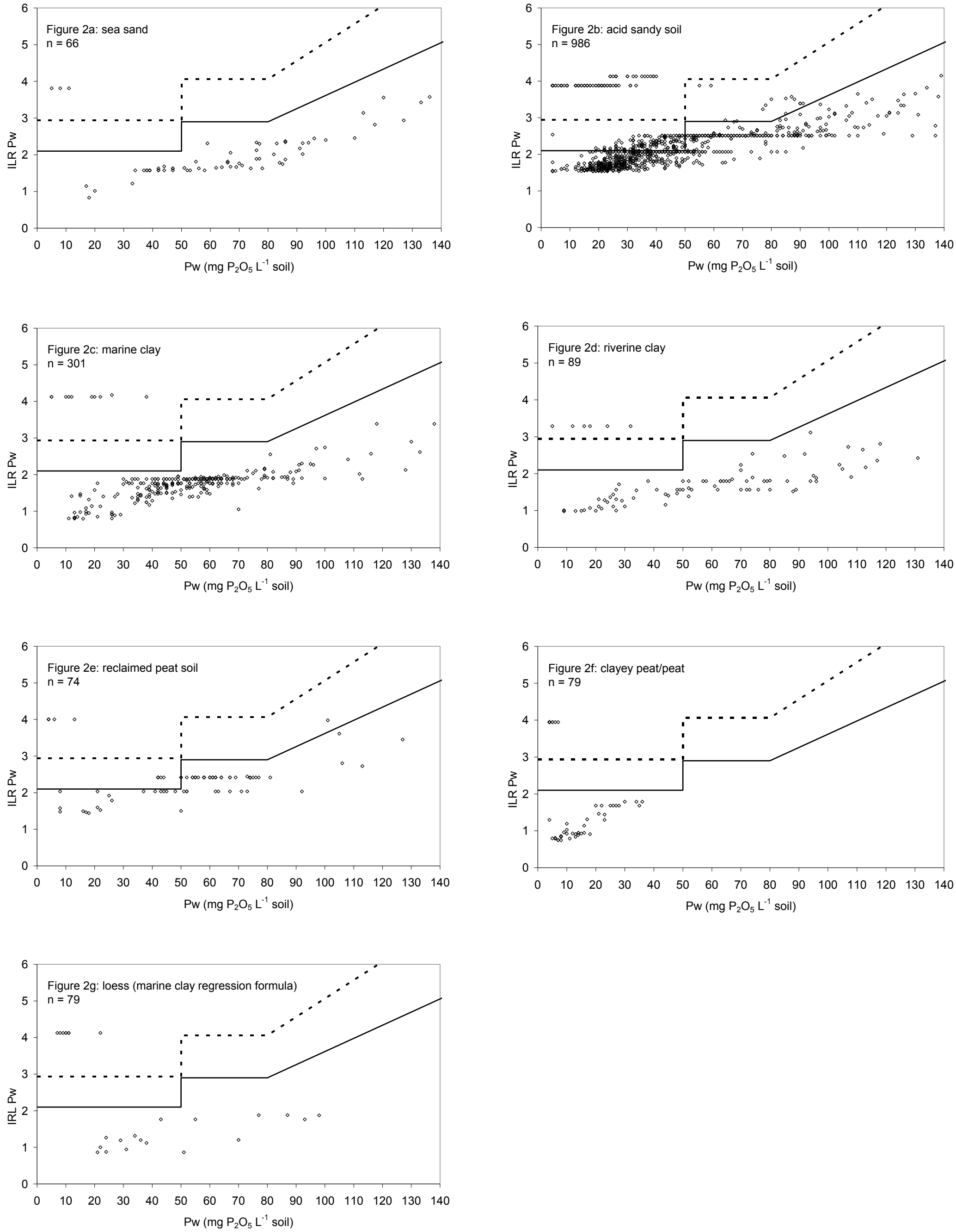


Figure 2 *Intra-laboratory reproducibility (ILR) values for Pw and predicted Pw for different Dutch soil types. Dotted line: ILR values used for Pw based on duplicate analyses (current practice); solid line: idem, for single Pw analyses; dots: predicted Pw values based on Table 5 and their calculated ILR (see text)*

In Figure 2, lines represent IRL values as function of measured Pw (dotted lines: duplicate analyses, which is current use; solid lines: single analyses). The dots indicate the predicted Pw based on the regression models presented in Table 5 and their calculated ILR values as explained above. The great majority of the IRL values of predicted Pw values are smaller than those based on the measured Pw values (Fig. 2). Only where P-$CaCl_2$ is just above the detection limit (dots left-side above the dashed line in Fig. 2), the IRL of estimated Pw is less accurate than the measured Pw. The accuracy for the analytical determination of P-Al is not limiting.

P-CAL and P-Olsen

P-CAL was predicted using P-Al and the ratio P-Al/P-$CaCl_2$ ($R_{adj.}^2$ = 0.88; S.E. = 3.04; Fig. 3a). A model including P-Al and P-$CaCl_2$ (without ratio) performed just as well (R^2_{adj}. = 0.87; S.E. = 3.17). SOM, pH, and clay% did not improve the model and subdividing into soil type did not either.

The fourth data set was considerably smaller than the other data sets. Still, also P-

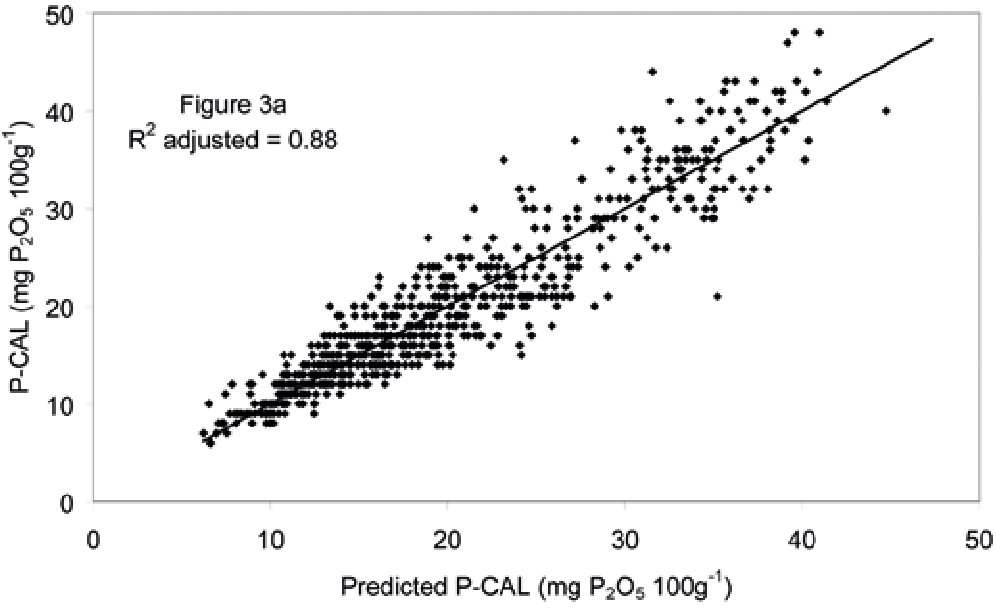
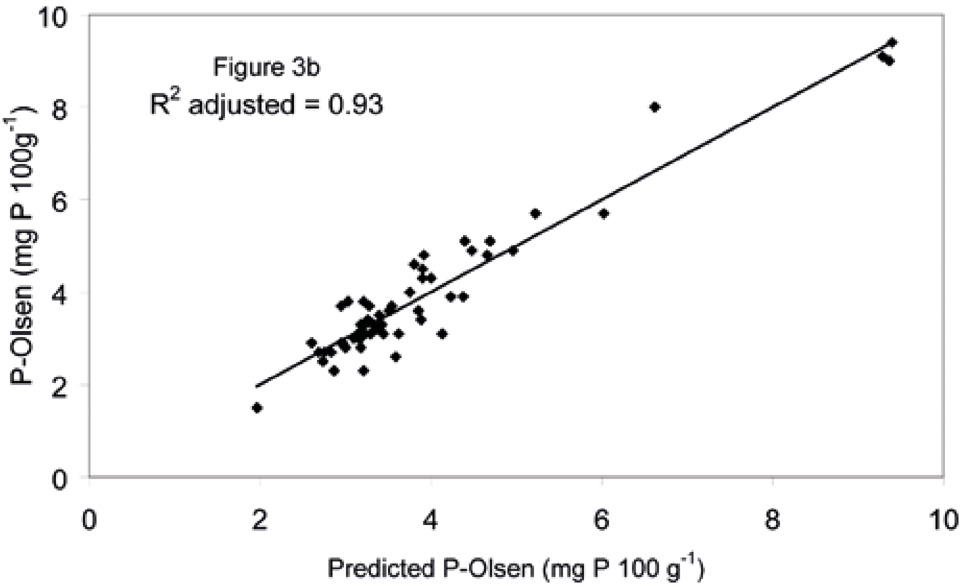


Figure 3 Comparison between (a) measured (mg P2O5 100 g-1) and predicted P-CAL, and (b) measured (mg P 100 g-1) and predicted P-Olsen on clayey soils. The predicted P-CAL is based solely on P-Al, and the P-Al/P-CaCl2 ratio, the predicted P-Olsen is based on P-Al and P-CaCl2.

Olsen could be predicted with an $R^2_{ajd.}$ of 0.85 on sandy soils (on basis of P-Al, P-$CaCl_2$, and pH), and without pH with an R^2_{adj}. of 0.81. P-Olsen on clayey soil (n = 61) could be predicted with an $R^2_{adj.}$ of 0.93 (on basis of P-Al, and P-$CaCl_2$; Figure 3b). Unfortunately, we had no additional information about the intra-laboratory reproducibility of P-CAL, and P-Olsen, and we could not compare standard errors of the predicted and measured values.



Discussion

Different soil tests reflect different soil P availability characteristics

Out of the numerous, worldwide available P tests, Neyroud and Lischer (2003) compared P tests and concluded that the amount of extracted P decreased in the order P-total > P-oxalate > P-Al > P-Mehlich3 > P-Bray > P-AAEDTA (ammonium acetate + EDTA) > P-DL (calcium lactate) > P-CAL (calcium lactate/acetate) > P-Olsen > P paper strip > P-AAAc (acid ammonium acetate) > P-Morgen > P-H_2O > P-CO_2 (CO_2 saturated water) > P-$CaCl_2$. The authors stated that mild extracting agents such as H_2O and $CaCl_2$ can be useful for immediate fertilization recommendation (intensity estimate of P availability) and harsher extracting agents (like P-oxalate or P-Al) for the long-term fertilization strategy (capacity estimate). In most countries still a single soil P test is used. Only using P-Al does not seem to justify the large differences in intensity which can occur within a given P-Al range. For example, within the P-Al category 30 – 40, P-$CaCl_2$ ranged from 0.4 – 2.8 mg P kg^{-1} in our datasets (10 and 90 percentile values, respectively). The same applies to P-CAL where we found P-$CaCl_2$ to range from 1.6 – 4.9 mg P kg^{-1} within P-CAL category 20 – 30. For P-Olsen, we found variations in P-$CaCl_2$ from 0.2 to 3.7 mg P kg^{-1} within P-Olsen category 3 – 4 (10 and 90 percentile values, respectively), confirming results of Delgado & Torrent (1997) and Delgado *et al.* (2010) who stated that P-Olsen is not very useful for estimating differences in plant available P in soils.

That two or more soil P tests may provide more insight into the soil P status and its relationship with crop response to P fertilization, has been suggested repeatedly (e.g. Kuipers, 1951; Van der Paauw, 1971; Ehlert et al., 2003; Quintero et al., 2003). The combination of P-intensity (i.e. P available for plant uptake), P buffering capacity, and P capacity has been subject of many studies (e.g., Van Rotterdam-Los, 2010; Celardin, 2003; Ehlert et al., 2003; Dalal & Hallsworth, 1976; Moody et al., 1988). The preference for a single soil test above two soil tests was often made for reasons of costs (Van der Paauw, 1971). With modern analysis methods this problem diminishes, especially when one extractant (0.01 M $CaCl_2$) can be used for several nutrients (Van Erp, 2002; Houba et al., 1990). An additional advantage of measuring many elements in a single extract is that interactions between nutrients can be taken into account in the fertilization recommendations (Van Erp, 2002).

Introducing new soil tests in practice

Conversion equations have been made before, for example Buondonno *et al.* (1992) calculated P-Mehlich3 with P-Olsen (and some other soil characteristics), Zalba and Galantini (2007) related P-Bray with P-Olsen; and Carmo Horta *et al.* (2010) related P-Al with P-Olsen; all with high $R^2_{adj.}$ (≥0.80). However, such conversion equations have not led to new or more uniform soil tests in practice yet.

Introducing a new soil test in practice is cumbersome, since much knowledge was gathered during the calibration and validation of most current soil tests, mainly in the form of many time-consuming fertilisation experiments (Voss, 1998). We circumvent the necessity of high investments for preparing new recommendations by introducing regression models between the old and new methods. Thus, the knowledge based on old fertilisation experiments can still be used, until it can be replaced confidently by insights directly based on the novel test. Such an introduction could be done by crop and soil type. Also Sims (1989) stated that the use of such equations represents a suitable interim measure.

We aimed at a predicted Pw, P-CAL, and P-Olsen with regression coefficients ($R_{adj.}^2$) between predicted and measured of at least 0.80. Only in the second dataset (Pw) additional soil characteristics were needed to obtain an $R^2 \geq 0.80$. For marine clay, also pH, and the contents of $CaCO_3$ and clay were needed, in addition to P-$CaCl_2$ and P-Al. Similar results were found by De Haas *et al.* (2005), who observed that the R^2 increased from approx. 0.70 to 0.80 by adding common soil characteristics to the regression equation. Still, in all final equations only P-Al, P-$CaCl_2$, and soil type are needed, resulting in regression models between R_{adj}^2 0.80 - 0.91.

Importantly, the standard error of the predicted Pw was lower than that of the measured Pw. This could not be tested for the P-CAL and P-Olsen because of lack of information on intra-laboratory reproducibility.

Stepwise implementation of new soil tests in practice

The third step would be the stepwise introduction of new methods and recommendations in practice. In The Netherlands, P fertilisation recommendation for maize has been based on Pw values until 2004. The Pw test values reflect both the intensity and capacity; it is not possible to separate intensity from capacity (Van Noordwijk et al., 1990). From 2004 onwards P-$CaCl_2$ and P-Al are measured in samples from maize land and subsequently reported to farmers (and their advisors), but the predicted Pw was also reported to the farmer and used for deriving the P fertilisation recommendations. At the same time the intensity/capacity-buffering concept was tested further in pot experiments and field trails (Bussink and Temminghoff, 2004; Bussink et al., 2007; Van Rotterdam et al., 2009). Results of these experiments were presented to the Committee for Fertilization of Grassland and Fodder Crops, and early 2011 the new system was approved (Anonymous, 2011), 7 years after introducing the dual soil P test values (P-$CaCl_2$ and P-Al) to the farmers. In the meantime, farmers and their advisors had become familiar with the new soil P test values so that the new P fertilization recommendation was a small step.

Benefits of using new and uniform soil P tests

There is a considerable advantage of this approach because P-Al and P-$CaCl_2$ are determined more accurately than Pw (Henkens, 1984; Bussink et al., 2003).) Indeed, our results show that predicted Pw is more accurate than measured Pw. Already at the start of the use of the Pw method problems were noticed (Van der Paauw et al., 1971; Henkens, 1984). It has been suggested that sampling a field every time in the same month and after the same crop in the crop rotation would diminish the problems of the Pw-based measurements, with the argument that effects of the previous crops were then excluded (Henkens, 1984). In addition to logistic difficulties, the results of reference samples in the laboratory of BLGG AgroXpertus and of the department of Soil Quality of Wageningen University do not endorse this suggestion. Reference samples are analysed several times every working day, during the whole soil sampling season (August – March). Since Pw is only used for routine analysis in The Netherlands, no further international information on laboratory quality is available. Throughout the years, BLGG AgroXpertus and the department of Soil Quality of Wageningen University investigated several possibilities for improving the Pw method without much success (Bussink et al., 2003).

Predicting one soil P test from different P tests enable international comparisons of P status. Using an extra soil test to the current soil test may also lead to improvements in the precision of fertilization recommendations. For example, given the considerable variation in P-$CaCl_2$ within a certain P-CAL or a P-Olsen category, fertilisation recommendations for P-CAL and P-Olsen may already improve by just adding an intensity characteristic.

Recommendations and implications

Knowing the importance of soil (P) fertility in relation to food production for the increasing world population, standardization of soil P tests should be an item in international debates on how to achieve food security. Only then good comparison of soil fertility (including soil P results) is possible and understandable for scientists, policy makers, and farmers. In addition, using the same soil test worldwide would create a database with crop response of unknown scale. With current concerns about depleting P resources (Heffer et al., 2006; Cordell et al., 2009) every effort to improve P efficiency by using these datasets would be commendable. Although efforts to uniform the large number of soil tests in for example the European Union (EU) (Copernicus project, Fotyma et al., 1998) has proven to be difficult, this still should be the ultimate goal. It therefore would be advisable for new international projects like Dairymen (www.interregdairyman.eu), where the effects of management on soil fertility is a research subject, to use the same soil tests everywhere, in addition to national tests. Predicted values will, perhaps for a long period, be needed to give local farmers and advisers handles to compare the new soil tests to the test they were used to, it will undoubtedly start the process of understanding these tests. The advantages of multiple soil tests for P should thereby be communicated extensively to farmers, their advisers and policy makers.

Chapter 7

FARMERS' PERCEPTIONS OF SOIL TESTS, FERTILIZATION RECOMMENDATIONS AND SOIL FERTILITY IN THE NETHERLANDS

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Abstract

Soil tests are indispensable in farm management, to obtain high crop yields and high nutrient use efficiency, to reduce nutrient losses to the environment and to increase carbon sequestration in soil. While soil tests are carried out in many countries for a long time already on a routine basis (once in about 4 years), there is surprisingly little information about farmers' perceptions towards these soil tests and soil test-based fertilization recommendations. Here, we report on a study investigating farmers' opinions about soil tests and fertilization recommendations, and about their concerns. A written questionnaire was developed and sent out to arable and horticultural farmers in five regions in the Netherlands. In total, 187 farmers responded (response of 20%). Interest in soil tests and fertilization recommendations was high; soil tests are regarded as the most important factor in realising a sound fertilization plan. Significant differences were observed in the appreciation of soil tests between farmers on sandy versus clayey soils. Farmers on clayey soils were more interested in mineral N test, while farmers on sandy soils were more interested in soil Mg status and micronutrients. Results of the questionnaires were intertwined with land use history and education level. Soil P status was considered most important followed by K status and soil organic matter (SOM). Despite the perceived importance of soil P status, most farmers (70%) had doubts about the current soil P test and associated recommendations. As a result, farmers strived for higher than recommended soil P values. Main concerns of farmers were a decreasing SOM content and soil P status, and deteriorating soil structure and soil life, suggesting that soil testing should pay more attention to these issues. In conclusion, farmers highly appreciate (more) soil tests as a management tool, but at the same time distrust soil P-tests. The latter implicates that more P is applied than needed, which puts additional pressure on the longevity of scarce P reserves.

Keywords:

Questionnaire, soil fertility, phosphorus, soil organic matter, arable farming, horticulture, perception study, decision tool

Introduction

Crops require 14 nutrient elements in specific amounts; these elements are essential for optimal growth and development of the crop (e.g., Marschner, 2012). Element uptake ranges from 0.01 to 1 kg ha^{-1} year^{-1} for micro nutrients such as copper (Cu), zinc (Zn), selenium (Se) to 10 to 500 kg ha^{-1} for macro nutrients such as nitrogen (N), sulphur (S), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) (Westermann, 2005), depending on crop type and yield. Commonly, most of the nutrients are supplied to crops by the soil. Soils high in fertility can supply sufficient nutrients to the crop throughout the growing season. Therefore, higher yields per unit of area can be realised on fertile soils than on low-fertility soils (e.g. Van Ittersum and Rabbinge, 1997; Johnston et al., 1986; Deoliveira et al., 1994; Patzel et al., 2000; Janssen and De Willigen, 2006). If nutrients in harvested crops are not replenished by fertilization, soil fertility will ultimately decline.

The level of soil fertility is assessed through soil tests. These soil tests are commonly done by professional soil labs at farmers' requests once in 3 to 5 years (Voss, 1998). A soil test report is commonly accompanied by a field-specific fertilization recommendation to improve and maintain the soil fertility status at agronomical optimal ranges.

In theory, soil tests play a major role in farmers' decisions on fertilization and soil management. However, farmers' perceptions of soil tests, fertilization recommendations and soil fertility are largely unknown. Also, the use and appreciation of soil tests by farmers have hardly been evaluated. Recently, Nesme et al. (2011) studied the key factors of fertilizer P use by farmers on the basis of soil tests; they found that few farmers used recommendations based on soil tests. Recently the importance of soil tests and fertilization recommendations have been emphasized for among others China, India, and Sub-Saharan Africa (Sutton et al., 2013), implicitly assuming that the soil tests and soil test-based fertilization recommendations are used by farmers to increase crop yields, soil fertility and nutrient use efficiency.

The objective of this study is to improve our understanding of farmers' opinions about soil tests and associated fertilization recommendations, and about their concerns related to soil fertility. A written questionnaire was developed, tested and subsequently sent to arable and horticultural farmers in several farming regions in the Netherlands. These regions have a different history, also related to nutrient surpluses, in part because of the availability of animal manure from nearby intensive livestock operations. The Netherlands is of interest since it has more than 80 years of experience with soil tests and fertilization recommendations, it has on average a high soil fertility level, and its agricultural production is among the highest in the world. We hypothesized that perception towards soil tests and the implementation of their results depend on key farming system characteristics. For this, we considered age and education of the farmer, crop rotation (intensive vs. extensive) and farm type (arable vs. horticultural and arable vs. mixed farming (i.e. rotating arable crops with grass)) and soil type (sand vs. clay). Age reflects experience of the farmer, education reflects knowledge of the farmer; both could affect the farmers' attitude to soil test results. Horticultural farming is more capital-intensive than arable farming, so more investments in soil research would be expected. Sandy soils are more susceptible to changes in soil fertility than clayey soils, so soil tests are possibly more needed on sandy soils. More insight in the use and appreciation of soil tests by farmers will hopefully improve the usability of current and future soil tests and fertilization recommendations.

Materials & methods

Agriculture in The Netherlands

The Netherlands is situated along the North Sea in the delta of the rivers Rhine, Meuse, Scheldt, and Ems. Of its surface of 34,000 km^2, about 20,000 km^2 is used as agricultural land. Most agricultural land is used for dairy farming (60% of the area), arable farming (33%), with potatoes, sugar beets, onions, winter wheat and flowers as main crops, and horticulture (5%), with leek, asparagus, cabbage, strawberries, apple and pear orchards as main crops (CBS, 2011). Arable land is mainly situated on carbonate-rich marine clay soils found in the southwest (province Zealand), north (provinces Friesland and Groningen) and in the centre (province Flevoland). A mixture of arable, horticultural and livestock farms is present on sandy soils in the south (province North Brabant). There are about 12,000 arable farms, and 10,000 horticultural farms (excluding glasshouse farms). These numbers are decreasing whilst average farm size is increasing (CBS, 2011).

We selected five typical arable farming regions (Figure 1): four regions with mainly marine clay soils all laying below sea level, and one region with sandy soils. The clayey soil regions differ in history. The province Zealand was already inhabited before the Roman Era, and has experienced cycles of flooding and reclamation of polders. The Northeast Polder (NOP) was reclaimed in 1942 and the polders Eastern Flevoland and South Flevoland were reclaimed in 1957 and 1968, respectively, all from the former Zuiderzee (IJssel Lake). The fourth clayey soil region is Groningen, along the Wadden Sea. This region has witnessed series of flooding and reclamation of polders during the last millennium. Arable land on sandy soils is also found in Groningen (in the southern part). The sandy soils of the province North Brabant is the 5th region (Figure 1).

Figure 1. *The Netherlands with the locations of the 5 selected regions.*

Questionnaire

Farm advisors were asked to give comments on draft versions of the questionnaire. Based on their feedback, the draft questionnaires were revised. The questionnaires (see ANNEX I) were sent to 200 farmers of each region. So, in total 1000 questionnaires were sent out. Farmers were selected at random out of the client database of BLGG AgroXpertus (Blgg), which is the leading laboratory for soil and crop analyses in the Netherlands (market share ~80%). This database contains information about location and type of farmers. Early 2010, the questionnaire was sent out by regular mail, together with a short introduction about the background of the study.

There were in total 29 questions, structured in 5 parts. Part 1 contained general questions (type and acreage of farm, crop rotation, age, level of education). Part 2 sought information about the use of information from soil tests and its appreciation (goal of soil tests, which test are important or lacking, how are results used for fertilization plans). Part 3 dealt with the use of animal manures and fertilizers (types, reasons). Part 4 dealt with the soil P testing (what is the target soil P status, how useful are different soil P tests). Part 5 was about soil fertility and soil quality in general (what are the main concerns). The emphasis on P in part 4 is because around the time of sending this survey, P legislation based on soil tests was introduced and also because there were initiatives to change soil P tests and associated recommendations

Data processing and statistical analysis

Mean values obtained in the different groups were compared by t-tests. Chi-square test (χ^2) statistics were generated for comparisons of frequencies of categorical data. Flaten et al., (2005) and Chataway et al., (2003) also used written questionnaires (both focussing on dairy farming) and they also used these statistical tools to test their hypotheses.

Results

General information

In total, 187 farmers responded (response of 20%). Farm size ranged from less than 20 ha to more than 80 ha. Small farms (<20 ha) were mostly located in North Brabant ($p<0.01$), large farms (>80 ha) in Groningen, Flevoland and Northeast Polder ($p<0.01$). The level of education varied between the regions. In Flevoland and the Northeast Polder, 90% of the respondents had succeeded agricultural vocational education and training or agricultural college. In Groningen and Zealand this was about 70%, and in North Brabant 50%. Most respondents were between 45 – 55 years (~35%), followed by 35 – 45 years (~25%), and 55 – 65 years (~25%). The age distribution of the respondents was comparable among the regions. All farms in Flevoland and the Northeast Polder had potatoes in their crop rotation, and were highest in percentage sugar beets (Table 1). The crop rotations of the arable farms in North Brabant included the common arable crops but also maize, peas, lettuce, carrots, and strawberry. The horticultural farms in North Brabant typically had a large diversity of crops, with strawberries, leek, asparagus, and lettuce being most common. Soil tests were used by 97% of our respondents.

Table 1a. Common crop rotations on arable farms in the five regions.

Region	Most frequent crop rotation					
	year 1	year 2	year 3	year 4	year 5	year 6
Groningen	potatoes	(winter)wheat	sugar beet	(winter)wheat		
Northeast Polder	ware potatoes	sugar beets	Carrots	ware potatoes	seed onions	winter wheat
Flevoland	ware potatoes	winter wheat	sugar beet	varias		
North Brabant	ware potatoes	maize	sugar beet	(winter)wheat		
Zealand	ware potatoes	winter wheat	Onions	suger beets	winter wheat	

Table 1b. Intensity of crop rotations, and the occurrence of potatoes, sugar beets, and wheat in the rotation, as function of region (percentage of respondents).

Region	Branch	Crop rotation, %							Crop in rotation			Respondents
									%	%	%	#
		1 : 1	1 : 2	1 : 3	1 : 4	1 : 5	1 : 6	1 : 7	Potatoes	Sugar beets	Wheat	
Groningen	arable	0	11	17	47	22	3	0	72	67	100	38
Northeast Polder	arable	0	0	30	24	11	35	0	100	79	80	37
Flevoland	arable	0	0	8	56	26	8	2	100	86	100	51
North Brabant	arable	0	21	0	44	21	14	0	64	64	57	16
	horticulture	13	37	13	25	13	0	0	13	13	0	20
Zealand	arable	0	0	4	33	37	25	0	84	63	92	25

Appreciation of soil tests

Arable and horticultural farmers rate soil tests and fertilization recommendations differently. According to arable farmers, the importance decreased in the order soil P status > K status > SOM > fertilization recommendations. In contrast, horticultural farmers had the opinion that soil Ca status was most important ($p<0.01$), followed by Mg status > K status > fertilization recommendation > P status > SOM.

When asked about the relevance of soil fertility status to different crops, one third replied: for all crops equally, while others mentioned a specific crop. Arable farmers found soil fertility status most important for potatoes (ware, seed, starch) > sugar beet > onions >> winter wheat. Also carrots, spinach, peas, tulips, and beans were mentioned. Horticultural farmers responded that soil fertility status is most relevant for strawberries and asparagus, likely related to the higher economic yield per hectare of these crops.

Table 2. Responses (in %;more than one answer was possible) to the question "What is missing on common soil test reports"?

Responses	Groningen	Northeast Polder	Flevoland	North Brabant Arable	North Brabant Horticulture	Zealand	The Netherlands
Nothing	49	32	33	31	24	44	37
Soil life	21	27	29	19	29	8	23
SOM quality	13	22	31	25	10	24	22
Soil structure	26	30	20	19	19	12	22
Micronutrients	15	14	22	25	29	12	19
Regional yields	10	14	14	13	10	8	12
Distinctness	5	5	8	0	10	16	7
Plant Pathogenic Nematodes	8	5	4	6	19	4	7
Calcium status	3	0	14	6	0	4	5
Other	5	0	2	6	10	4	4

When asked 'what is missing?', 37% replied 'nothing' (Table 2). Other respondents indicated that information was missing about (i) soil life, (ii) soil structure, (iii) quality of soil organic matter and micronutrients. Respondents from Zealand notably missed information about the SOM quality, while respondents from Groningen, Flevoland and Brabant mentioned soil structure parameters.

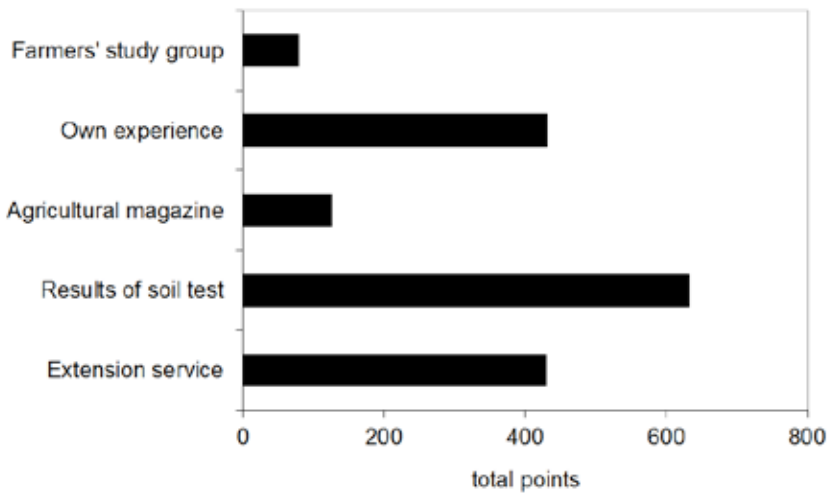


Figure 2 Responses to question 'who or what is most important when making a fertilization plan?' Results differ significant from each other ($p<0.01$), except for 'Agricultural magazine – Farmers' study group' ($p<0.05$), and 'Own experience – Extension service' (not significant).

When asked 'who or what is important for making fertilization plans', the responses were, in decreasing order of importance: soil test results > extension services = own knowledge > agricultural magazines > farmers' study groups (Figure 2; question 10 in ANNEX I). Respondents with a BSc and/or MSc degree placed their own knowledge as equally important as the results of soil test, and appreciated the results of soil tests less than those without such degrees ($p<0.001$; see ANNEX II). Farmers using soil mineral N tests attached significantly ($p<0.001$) more importance to extension services (ANNEX II) compared to farmers using results of basic soil tests only.

Fertilizer and manure use

Arable and horticulture farmers have the choice to import fertilizer and/or animal manure. While fertilizers may constitute 5-20% of the total costs in arable farming, manure was available for free or even with a goodwill fee during the last decades. A total of 68% of the respondents used mineral P fertilizers (range 44% in Groningen to >80% in the Northeast Polder and Flevoland; Table 3). Furthermore, 78% of the respondents used mineral K fertilizers and 96% mineral N fertilizers. A total of 67% of the respondents used pig slurries, especially in North Brabant and Zeeland, where its availability is largest.

Most respondents rated the value of animal manure in the following order of importance: organic matter supply > nutrient supply >> source of income > suppression of soil-borne diseases. In Groningen, nutrient supply was more valued than organic matter supply ($p<0.01$).

Table 3 Usage of mineral fertilizers, animal manures, and composts (%).

	Groningen	Northeast Polder	Flevoland	North Brabant Arable	North Brabant Horticulture	Zealand	The Netherlands
N-mineral fertilizer	100	94	94	94	95	100	96
P-mineral fertilizer	44	81	86	50	52	76	68
K-mineral fertilizer	64	92	82	75	71	80	78
Ca-mineral fertilizer	21	6	20	31	24	8	17
Pig manure	64	69	65	88	43	80	67
Poultry manure	28	17	31	6	0	0	18
Dairy cattle manure	23	11	31	56	38	20	27
Compost	21	44	24	25	43	8	27
Other[&]	23	14	10	25	33	16	18

&: champost, earth foam, duck manure, horse manure, Mg-artificial fertilizer

Appreciation of soil phosphorus status

When asked 'what is your reference for P fertilization?', 35% of respondents replied the soil P status, 30% responded the permissible application amount of animal manure and another 30% responded crop type (Figure 3; question 19 ANNEX I). In total, 70% of the respondents aimed at improving the soil P status, though with significant differences between regions and farm types. In the Northeast Polder, 90% of the respondents aimed at a higher soil P status than recommended, but less than 30% for the horticultural farmers in North Brabant reported this strategy. None of the respondents aimed at a soil P status below the agronomical optimal range. Most important tools to improve P status were animal manure >> mineral fertilizers >> green manure > compost > crop rotation.

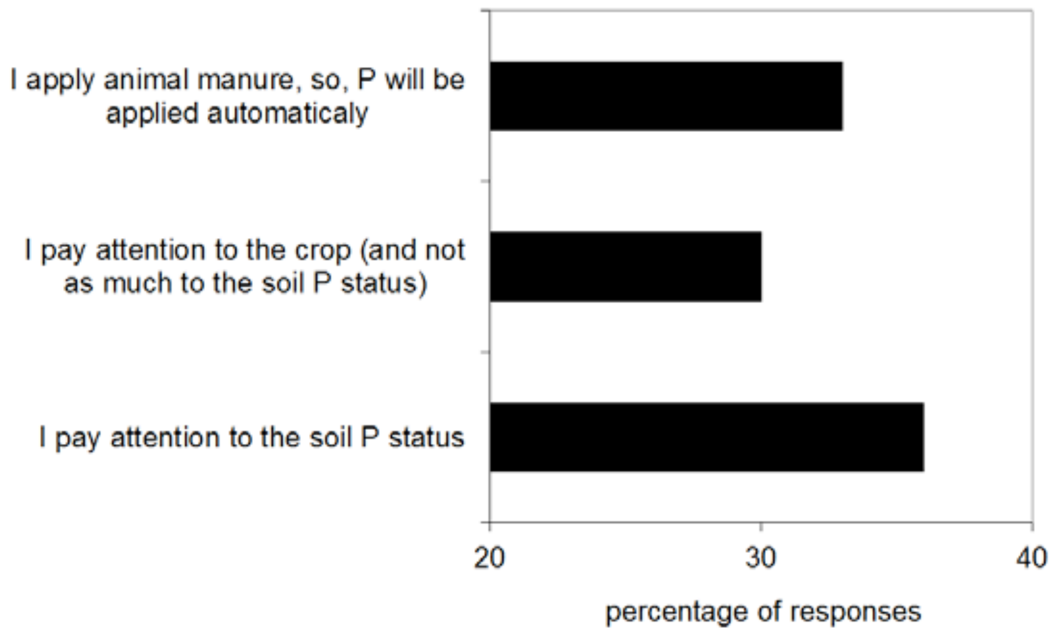


Figure 3 Responses to question 'what is reference for P fertilization?' The responses do not significant differ from another.

More than half of the respondents had the opinion that soil P status will decrease following the implementation of P application limits as function of soil P status from 2010 onwards. Surprisingly, 73% of the respondents felt unsure about the diagnostic value of the soil P test for plant available P. Uncertainty about the value of the soil P test was largest in the Northeast Polder and lowest in Brabant-horticulture.

There were two questions about the soil P tests (several answers were allowed). A test to indicate the capacity of the soil to supply crops with P throughout the season is considered important for 57% of the respondents. Forty per cent of the respondents indicated that no matter the soil P status and what is recommended, a starting gift of P fertilizer is always needed. For 14% of the respondents the methodology of the soil tests are of little importance, as long as the recommendations are good (see also ANNEX II). In a second question about soil P tests, 64% of the respondents indicated that information about P intensity tests (i.e., concentrations of plant available P) is important. About 25% of all respondents indicated that more communication about soil tests and recommendations is necessary.

Soil fertility

More than 90% of the respondents indicated that fertilization practices have changed during the last 10 years due to legislation on manure use, more attention for SOM status, soil structure, micronutrients, and because of increasing fertilizer prices and decreasing animal manure prices. Farmers in Flevoland and Zeeland paid more attention to SOM and soil structure than farmers in other regions, while arable farms on sandy soils paid significantly more attention to micronutrients than respondents on clayey soils. The vast majority of farmers indicated to aim at improved soil fertility, in the first place by using animal manure/compost and in the second place with crop rotation (Table 4).

Table 4 Frequency of responses (%; more than one answer was possible) to the question "what actions are taken to improve soil fertility?".

	Groningen	Northeast Polder	Flevoland	North Brabant Arable	North Brabant Horticulture	Zealand	The Netherlands
Nothing, soil fertility is good	13	3	4	6	10	0	6
Currently nothing, but I used to	5	6	0	6	0	4	3
Use of animal manure/ compost	74	86	78	81	76	80	79
Exchange with grassland	8	8	8	19	10	0	8
Crop rotation	21	53	65	44	24	68	47
Other (e.g. green manure)	28	22	25	13	24	32	25

Possible decreases in SOM and soil P, and a possible deterioration of soil structure and soil life are future concerns to farmers (Figure 4; question 23 in ANNEX I). Respondents without BSc and/or MSc degrees were more worried about SOM and soil structure than respondents with BSc and/or MSc degrees, while the latter were more concerned about plant parasitic nematodes (ANNEX II). Especially respondents with intensive crop rotations had worries about plant parasitic nematodes. Respondents from Groningen and Northeast Polder were most worried about soil structure and nematodes ($p<0.01$).

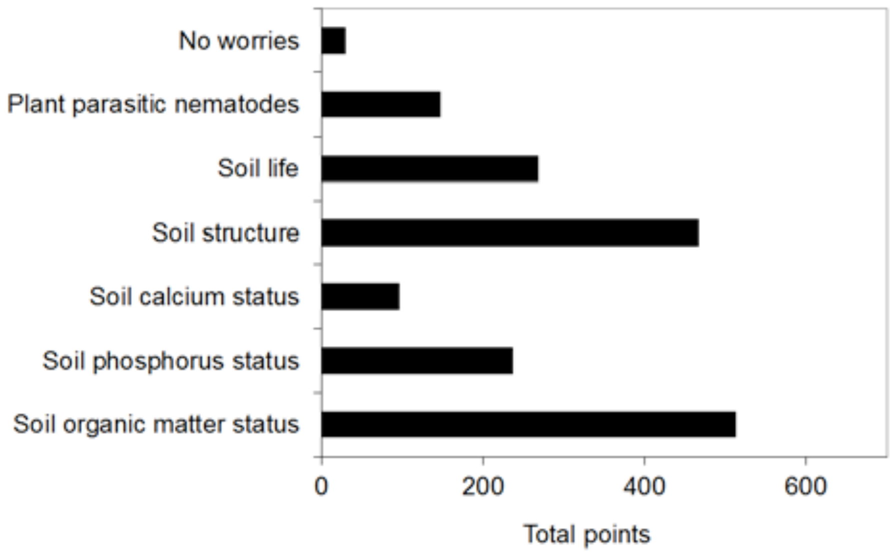


Figure 4 *Responses to question 'What is most worrisome regarding soil fertility in the future?'. All significant from another with p<0.01, except for Soil P status – Plant parasitic nematodes (p<0.05), and except for SOM status – Soil structure, and Soil P status – Soil life, and Soil Ca status – Plant parasitic nematodes (not significant).*

Discussion

Main implications

The farmers in our sample population appreciate soil P test values, but at the same time distrust the diagnostic value of the soil P test. Also, the farmers fear that SOM values decrease, although there are no solid data to sustain this fear, as mean SOM contents (and P contents) and crop yields in the Netherlands are among the highest in the world. Evidently, our farmers are concerned about their soils, more than one would expect on the basis of soil test reports and associated fertilization recommendations. Farmers do not accept a possible decrease of soil fertility indices, even when the level is high (e.g., Patzel et al., 2000). These findings are important, as there is a great need to increase nutrient use efficiency in the world (e.g., Sutton et al., 2013). Our findings suggest that increasing nutrient use efficiency by 20% by the year 2020 (Sutton et al., 2013) requires tools to convince farmers to do so.

There are as yet not many studies available to reflect on and to evaluate whether our results are biased. Perception studies about soil test and fertilization recommendations are uncommon in agriculture. Nesme et al (2011) found that 80% of the respondents used soil tests; in our study >95% of the respondents used soil tests. The response rate of our written survey (20%) was comparable with those obtained by Vanclay and Clyde (1994), and Hayman and Alston (1999), but was lower than that of Chataway et al. (2003). A reminder letter and the use of new questionnaire techniques by e-mail might have improved the response rate. Doll and Jackson (2009) had a response rate of 56% (after a reminder), but Brook and McLachlan (2006) obtained a response rate of 25% after a reminder, which is not much different from our study.

Notions on soil tests differ by region and farm system

Results of soil tests reported to farmers are usually accompanied with soil-specific and crop-specific fertilization recommendations. As such, soil tests seem straightforward in their application, but in reality it is only one of multiple information sources a farmer gets to decide on managing soil fertility. Other possible stakeholders are inorganic and organic (including compost) fertilizer suppliers, soil conditioner suppliers, study groups, extension services, and family members and neighbours. Reasons to deviate from soil test-based fertilization recommendations include own observations and notions about crop responses to soil fertility and fertilization, field-specific characteristics, and cultivar-based differences. The question we put forward here is whether farming system, as characterized by crop rotation, soil type, size, and farmers' age and education, interacts with appreciation of soil test results and the recommendations based on that. Our results indicate that especially soil type leads to significant differences in appreciation (most significant differences between 'arable farming sand' and 'arable farming clay'; ANNEX II). Arable farmers on sandy soil appreciated information about the soil Ca-, Mg-, K- and micronutrients status more than arable farmers on clay soils.

Farmers on clay soils considered SOM status significantly more important than their colleagues on sandy soils. These differences were however partly intertwined with farm size (more small farms on sandy soils), soil P status (higher soil P status on sandy soils: Reijneveld et al., 2010a), (lower) education and age (farmers were on average older on sandy soils than on clay soils).

Irrespective of these soil type based differences we observed that arable farmers find soil P status most important.. The fact that soil P status was valued as the most important soil fertility characteristic is likely related to the introduction in 2010 of P application limits that depend on soil P status. At the same time, the value of the soil P test to establish plant available P was questioned by ~70% of the farmers. This is comparable to the results of Nesme et al. (2011), who found that soil P value was perceived as more important than the recommendation derived from this value. This perception may have contributed to the strive for supra-optimal soil P values and P applications (70% of the respondents). In contrast, Nesme et al. (2011) reported that the amount of P used by farmers was lower than recommended. Further, farmers indicated to want to apply a P starter at the beginning of the growing season, irrespective of soil test results.

Various suggestions have been made for improving soil P test and P fertilization recommendations. Most studies suggest the use of two or more soil tests, so as to obtain more insight in soil processes and soil P pools (e.g. Ehlert et al., 2003; Achat et al., 2009, Van Rotterdam – Los, 2010; Schröder at al., 2011). Implementing new techniques and soil tests was endorsed by most arable farmers. Irrespective of soil type, an equal number of farmers expressed preference for a 'plant-based' P fertilization strategy as for a 'soil-based' fertilization strategy. This contrasts with results obtained by Nesme et al. (2011); they found that most farmers opt for a 'plant-based' fertilization strategy. 'Soil-based fertilization' is a strategy to improve soil fertility status on a longer term, whereas 'plant-based fertilization' can be seen as investments on year-level, i.e. direct investments in the current crop. The ability of Dutch farmers to choose for both a plant- and soil-based-strategy likely reflects the availability of cheap animal manure as a source of SOM and nutrients. In contrast, crop rotation, residue management and fertilizer applications are regarded as important but costly measures to sustain SOM, P, and K levels in areas with little animal production (Wivstad et al., 2005).

Farmers make fertilization plans mainly on the results of soil tests. Some farmers though relied on extension services and own knowledge, and/ or on agricultural magazines and farmers' study groups. This is somewhat in contrast with Morton (2011) who reported that factors determining the application rate of animal manure were in the order of: farmers' own judgement and experience (38%) > crop requirements (29%) > soil test (12%) > consultant's recommendation (6%).

Main concerns regarding soil fertility

A possible decline of SOM content and soil structure worries arable farmers (Figure 4), which is in line with the findings of Van Dam et al. (2006) and Dieleman (2012, pers. comm.). Scientific reports about declining SOM contents in the world (Hartemink, 2003; Bellamy et al., 2005; Riley and Bakkegard, 2006) may have had an effect on their own concern. However, average SOM contents are relatively high in the Netherlands, and they do not show declining trends (Hanegraaf et al., 2009; Reijneveld et al., 2009).

In the presence of N and P application limits, soil structure, drainage and SOM become more important to maintain or increase crop yields (Hanegraaf et al., 2005; Haneklaus et al., 2005). Not surprisingly, our respondents indicated that information about soil structure and soil life are missed on current reports. However, by introducing more soil characteristics, the amount of information increases and may make recommendations more complex. We found that farmers who have both basic soil tests as well as mineral N soil tests appreciate the role of extension services significantly more. Apparently further explanations by extension services are needed especially when various soil tests are combined. Besides a more significant role for extension services, integration of the results of soil tests in decision support systems for optimal nutrient and SOM management are options, and to some extent already available (Burgt et al., 2009; Nutrinorm.nl 2012; Anonymous, 2012). Decision support systems can embed fertilization recommendations and may consider differences between potential yield and likely attainable yields, as function of weather conditions (Ros, 2011). However, the many examples of decision support systems that simply were not used, illustrate the resistance of farmers to have their decision processes by-passed. If on the other hand the decision support system is designed to serve as a tool to assist or adjust farmers' decision process than its use may increase (McCown, 2002; 2005). These applications should therefore, in our opinion, only be seen as an additional tool for making farm management decisions.

Conclusions

This study explored farmers' perceptions related to soil tests and fertilization recommendations in the Netherlands. It is one of the first studies that made an integrated assessment of nearly all soil fertility aspects that are interesting to farmers. We conclude that:

- Results of soil tests are appreciated by farmers; soil tests form an important ingredient for setting up a fertilization scheme.
- The most appreciated soil test is the soil P test, which on the other hand is also distrusted as predictor of plant available P..
- Farmers show interest in additional soil characteristics, especially regarding soil biological and physical characteristics. Such additional information will require more efforts of advisors to assist farmers with interpretation of the soil test. Ultimately, such an extended soil test could be integrated in a decision support system which includes, among others yield potential and weather information.

Acknowledgements

We greatly thank the farmers who responded to the survey.

Chapter 8

GENERAL DISCUSSION

Introduction

On fertile soils, high-yielding crop production systems can be built (Van Ittersum & Rabbinge, 1997). Such systems with high yields per unit of area are indispensable to feed the increasing world population, which increasingly relies on diets rich in animal-derived protein. The FAO recently estimated that the world's total crop production has to increase by 50 to 70% between 2010 and 2050 (FAO, 2012).

Large areas in the world still have low and/or declining soil fertility, which may contribute to soil degradation and declining yields (e.g., Hartemink, 2003; Heikkinen et al., 2013; Baruah et al., 2013; Kagabo et al., 2013). Increasing soil fertility levels requires investments and inputs in terms of appropriate fertilizers, manures, crop husbandry and soil cultivation practices. At the same time, environmental problems may arise if soil fertility and crop yields are increased excessively (e.g., Sutton et al., 2013). Hence, the challenge is to find and maintain soil fertility at a level that allows high crop yields while nutrient losses are acceptable.

The subject of this thesis relates to the question how the soil fertility status and its spatial and temporal variations in the Netherlands can be interpreted. The Netherlands is of interest because of its intensive agriculture and because governmental regulations have limited manure and fertilizer applications during last few decades.

In this final chapter, I present the main findings of my research, and discuss these to answer the following questions:

A) What is the current soil fertility in the Netherlands?

B) Is there room to improve the soil fertility status?

I finish with some final considerations, conclusions, and recommendations.

Soil fertility in the Netherlands

Soil organic matter

Soil organic matter (SOM) is generally considered as the most important element of soil fertility (Allison, 1973; Bauer and Black, 1994; Davidson, 2000), because of its effect on physical (e.g., soil workability, water holding capacity, root penetrability), chemical (e.g., cation exchange capacity, P adsorption, complexation), and biological (e.g., soil biodiversity, disease suppression, N and S mineralization) components of soil fertility.

There are wide-spread fears that the SOM content of agricultural land in the Netherlands is declining (e.g., Van Dijk et al., 2007; Van der Schoot & De Haan, 2012; Anonymous, 2013a; Chapter 7) due to soil tillage, climate change and manure application limits. Yet, I found that the mean SOM content of mineral soils is relatively high and remained stable or even tended to increase (Chapters 2, 4, and 5). Average SOM content of mineral soils in the Netherlands is 8.1% for grassland (0 – 10 cm; reference years 2007 – 2008; Reijneveld et al., 2010b) and 4.3% for arable land (0 – 25 cm; reference year 2004; Chapter 2). With that, mean SOM contents of mineral soils in the Netherlands are at the higher end compared to other European countries (EIONET data collection, 2010). For example, mean SOM content of mineral soils in arable land in Denmark is 4.0% (Heidmann et al., 2002), in Flanders 3.8%, and in Czech Republic 2.9% (Sáňka & Materna, 2004; pers. comm. T. Losák). Average values in the Netherlands are also above the SOM content of 3.4% that is often believed to be the 'critical' threshold level (Loveland & Webb, 2003). However, scientific evidence for such a critical threshold value is limited; it likely depends among others on soil structure (Loveland & Webb, 2003).

There were considerable regional differences in SOM content and its development in time. For example, SOM remained stable on arable soils in the Northeast polder (median 2.3%; Chapter 4), in the ley farming eastern part of the Netherlands (median 6.3%; Chapter 5), and on arable soils in the south western part (Zealand) of the Netherlands (2.4%; Chapter 2). However, also areas with declining SOM contents were observed: grassland in the north of the Netherlands faced a decrease from 15 to 9% in 27 years (Chapter 2; Reijneveld et al., 2010b). In general, regions high in SOM tended to decline while those low in SOM remained stable or had increased in time (Chapters 2, and 5).

Decreasing SOM levels are likely related to improved soil drainage, which started from the first half of the 20^{th} century, leading to accelerated SOM decomposition (Kortleven, 1963). This holds especially for peat soils, which were not included in my study. Recent inventories indicate a very significant decrease of the peat area in the Netherlands (e.g. Rienks & Gerritsen, 2005; De Vries et al., 2008b), which was related to increased (ground) water management. Reclaimed peat soils in the north-east of the Netherlands are also rather high in mean SOM content (~12%; Chapter 2) but they remained stable.

The on average stable or slightly increasing mean SOM contents in mineral soils in the Netherlands are in contrast with results of inventories in England, Wales (Bellamy et al., 2005), Flanders (Sleutel et al., 2003; Mestdagh et al., 2004; 2006), Brittany (France) (Anonymous, 2013b), Franche-Comte (Saby et al., 2008), Austria (Dersch & Böhm, 1997), southeastern Norway (Riley & Bakkegard, 2006), Finland (Heikkinen et al., 2013), and Bavaria in southern Germany (Capriel, 2013). This remarkable difference may reflect the relatively large external organic inputs into agricultural soils in the Netherlands, mainly in the form of animal manure (approx. 40% of the total input of organic matter), and crop residues from grassland and arable crops (Chapter 2).

Despite the relatively high mean SOM status, many farmers place SOM first on the list of 'future worrisome' soil fertility aspects (Chapter 7), independent of region and soil type. Farmers also indicated that they are eager to obtain more information about SOM quality. These farmers' concerns about SOM are likely related to the current legal restrictions that limit manure and fertilizer N and P use and thereby limit the input of organic matter from external sources. Likely, current farmer's worries are based on expected changes; indeed, it cannot be excluded that mean SOM levels will decline in future if manure and fertilizer limits become more strict.

Soil phosphorus

Soil phosphorus level is, next to SOM and pH, a main soil fertility characteristic. Adequate levels of plant-available soil P are needed for early root development, crop development and growth, including seed formation. Uptake of P by plants is very sensitive to its concentration in the soil solution (e.g. Barber, 1982; Marschner, 1985; Holford, 1997).

In the period 1971 – 2004, average soil P status of arable land (using soil Pw test) increased from the agronomical classification (ample) 'sufficient' to (fairly) 'high'. By the end of the study period, average Pw had increased to on average 53 mg P_2O_5 L^{-1} (Chapters 3 and 4). Average soil P status of grassland (using P-Al test) remained within the optimal range during the last 4 decades (Chapters 3 and 5; Reijneveld et al., 2010c) on 42 mg P_2O_5 100 g^{-1}. Although the P-Al method is the most used method in Europe (beside the Netherlands also in Sweden, Norway, Belgium, Portugal, Estonia, Latvia, Lithuania, Hungary, Slovenia, Croatia, Serbia, Montenegro, Romania, Bulgaria) (pers. comm. P. Csathó; Chapter 6), there is no mutual consultation between these countries about developments in soil P-Al status and also no joint data-base with soil P-Al data. Still, some comparisons can be made. Mean soil P-Al status in the Netherlands is comparable to Belgium (pers. comm. J.Bries, 2013), but higher than in for example Latvia (P-Al 18 – 25 mg P_2O_5 100 g^{-1}; Jansons et al., 2002) and Hungary. In most Central- and Eastern European countries P-balances were positive between 1960 – 1990 and negative thereafter, following the economic and political changes in the early 1990s. As a result soil P-Al increased until the 1990s and decreased thereafter (Csathó & Radimszky, 2002).

The drastic decrease in P application rates (Figure 1) in the Netherlands, because of legislative measurements since 1984, did not yet have a significant effect on the mean soil P status. However, restrictions on manure and fertilizer applications did contribute to the improvement of the quality of surface water bodies (Willems & Van Schijndel, 2012; Hooijboer & Klijne, 2012).

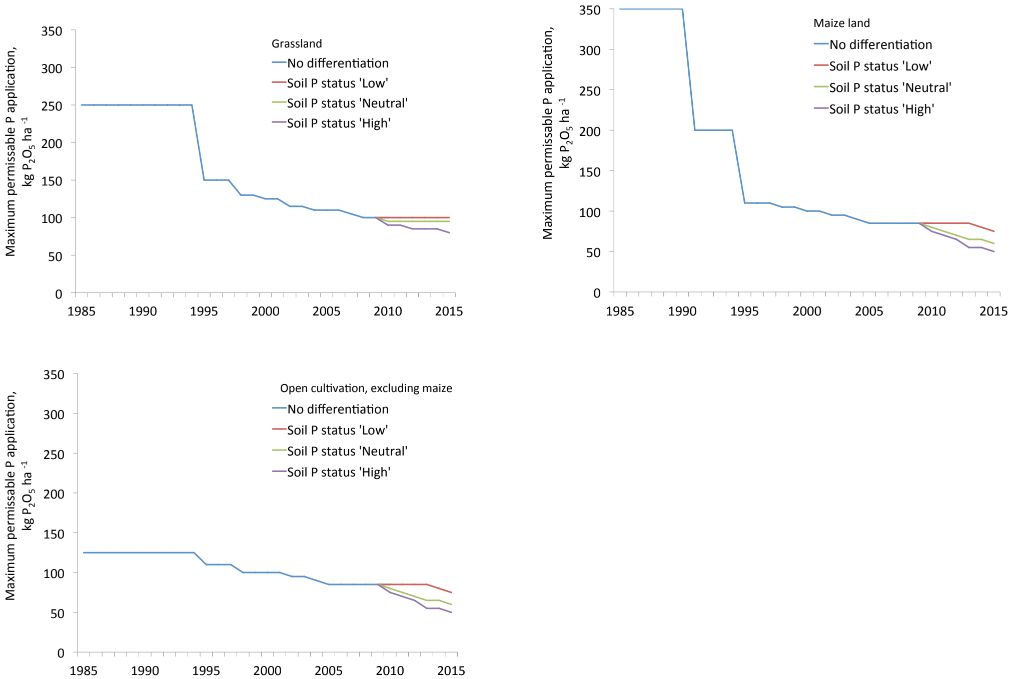


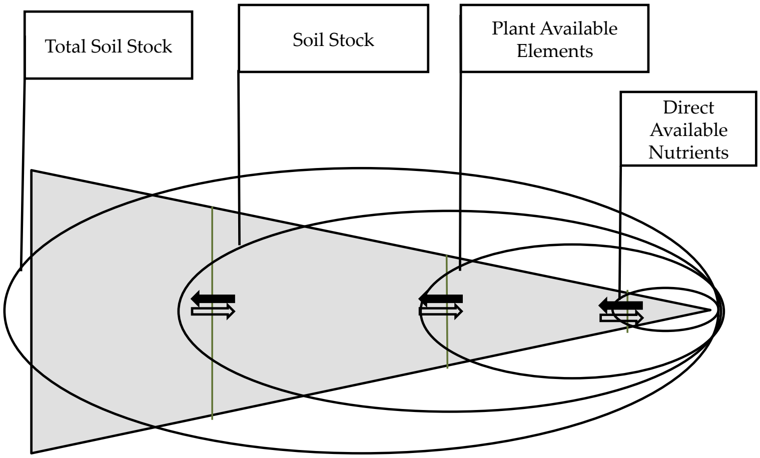
Figure 1 *Permissible P application for a) grassland, b) maize land, and c) open cultivations (Willems & Van Schijndel, 2012).*

Soil P levels are strongly related to land use; they increased in the order bulb fields < grassland < arable land < maize land < horticultural land. Such land use dependent differences in soil P are well-known (Mayer, 1895). A high soil P status seems typical for horticulture, which may be explained by the high P demand of some horticultural crops within a short growing period, and the relatively high economic value of these crops, making supra-optimal fertilization an 'insurance' against a possible nutrient shortage (Eriksson et al., 1997; Withers et al., 2001; Cahoon & Ensing 2004; Ketterings et al., 2005; Uusitalo et al., 2007; Lemercier et al., 2008).

For all soil types, regions and land uses, a wide range in soil P levels was found. For example, some 5% of the sampled grasslands had P-Al < 20 (low), and some 2% had P-Al > 99 mg P_2O_5 kg 100 g^{-1} (Chapter 3). Also, variation within and between farms is large and tended to increase over time as we showed for arable land in the North East Polder (Chapter 4). Variation between fields within a farm may be related to the history of fertilization; fields nearby the farm received more manure.

The steady state of P-Al on grassland compared to a rising Pw on arable land is in part related to a difference in the soil test methods; the P-Al method is based on a harsher extract agent than the Pw method. With P-Al a larger fraction of total soil P is extracted compared to Pw. Furthermore, the relative stable soil P status on grassland may also be explained by the rather shallow sampling depth (0-5 cm, and from the year 2000 0-10 cm), leaching of soluble P from the top soil to the subsoil, and to the common practice of ploughing and reseeding of the grassland (Chapter 2). Unfortunately, there is not much information about P accumulation in the subsoil, i.e. in soil layers below the top 10 cm.

Transformation processes of extractable to non-extractable P forms through precipitation and formation of quasi-irreversible sorbed P (e.g. Delgado & Torrent, 2000; Schoumans et al., 2004; Cao &Harris, 2008) are important. This leads to relatively stable levels of Pw and P-Al, while total soil P may increase (Murphy & Riley, 1962; NEN 5768, 1992; NEN-ISO 15681, 2004; Figure 2). However, total P is not a soil test commonly carried out for farmers. Thus, to get more insight in the accumulation (or depletion) of P in the soil profile total P analysis should be used more frequently, e.g. as part of a monitoring program.



Method	← P-total →	← P-Al →	← P-$CaCl_2$[#] →	← P-$CaCl_2$^ →
Result	250 mg P_2O_5 100 g^{-1}	40 mg P_2O_5 100 g^{-1}	1.5 mg P kg^{-1}	0.5 mg L^{-1}
Kg ha^{-1}	3400 P	545 P	4.7 P	2.5 P
	Soil Quantity		**Soil Intensity**	

 # 0.01 M 1:10 CaCl2 in dried soil (Houba et al., *1990)*

^ 0.01 M 1:2 CaCl2 in fresh soils

Figure 2 The soil quantity, buffering capacity, and intensity concept presented visually for P. The arrows indicate the buffering and binding processes which depend among others on Fe, Al, and Ca. Typical analysis results and amounts of P per hectare in the soil layer 0 – 25 cm are given (see also Van Rotterdam-Los et al., *2013).*

The steady state of soil P status on grassland is reflected in the P contents of herbage silage. The average P content of silage (4.0 g P kg DM-1) was rather constant during the period 1996 – 2009, and the 90 percentile values were never above 4.7 g P kg DM1, being just above the broad optimal range of 3.0 – 4.5 g P kg DM-1 (Chapter 5).

The steady increase in soil P(w) status towards above agronomical P ranges is based in part on the low confidence farmers have in soil P tests (Chapters 4 and 7). Another factor is that the price of P fertilizers (Figure 3) has been low relative to the value of crop yields. The price of animal manure was not high either: arable farmers have been receiving money for taking pig slurry for most of the last two decades (www.mestportaal.nl). Besides, there is no agronomical risk of applying P at levels above the agronomical optimum. Hence, applying more P than recommended could be seen as a no-regret security strategy.

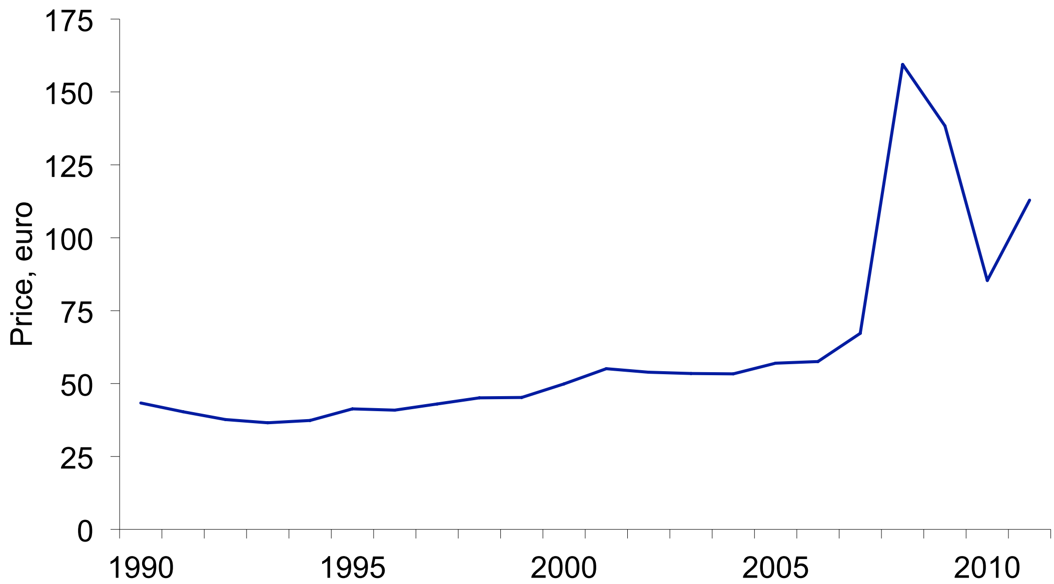


Figure 3 Development of price of artificial P fertilizer (price per 100 kg P2O5) (LEI, 2013

Soil pH

Soil pH influences the availability of various (micro) nutrients to plants, the effective cation exchange complex (ECEC; e.g. Curtin & Rostad, 1997), and affects soil microbial composition. For arable land on marine clay soils pH-KCl was relatively high (~7.4), while it was relatively low on reclaimed peat soils (~4.9). Mean soil pH on grassland varied between 5.4

(sandy soils) and 6.3 (marine clay soils in the north) (Chapters 2, 4 and 5). Mean values were within or just above the optimal ranges established for a given soil type and SOM content. For grassland, soil pH remained stable in the last decades, but with regional differences (Chapters 2 and 5). For example, soil pH of grassland on sandy soils significantly increased towards the upper end of the agronomical optimal range. In contrast, for 75% of the analysed maize fields on sandy soils, soil pH was below optimal levels (Bakker & Hensgens, 2004).

Other soil fertility characteristics

Soil K status increased on many soils during the last few decades (Chapters 4 and 5) although the increase slowed down in the last decade (Chapter 5), probably because of decreased manure and fertilizer application (Chapter 1). Average soil texture ranged from <8% clay on sandy soils and reclaimed peat soils to 29% clay on marine clay soils in the north, and 35% on riverine clay soils in the centre of the Netherlands (Chapter 2). On marine clay soils the maximum observed clay content was 43% (Chapter 6). $CaCO_3$% slightly decreased ($p < 0.05$) in the Northeast Polder (Chapter 4). Median values on marine clay were ~5% (Chapter 6).

Uncertainties

The data used in this study were based on the database of the leading laboratory in the Netherlands (BLGG). For example, in Chapter 3, results of approximately 5 million records of soil P analyses were used. Careful reflections are needed to be able to conclude whether it was unbiased, i.e., representative for the Netherlands (as discussed in Chapters 2, 3, 4). One of the main issues is that soil samples in the databases had been taken on farmers´ requests. It is possible that only farmers having a particularly strong interest in soil fertility preferably ask for soil tests, or alternatively farmers who assume that their soil is nutritionally out of balance. The composition of the database could also be affected by the influence of local traditions or behaviour of regional extension services. To test these potential problems, I therefore compared the database with a set of data from new clients in Chapter 3. These new clients never before had done any analysis at BLGG, but had to do so because of measures required by new legislation. This comparison indicated that the frequency distributions between the regular client and new-client databases were rather similar.

Is there room to further improve the soil fertility status?

On-going interest in soil fertility

The number of soil samples can be seen as an indirect indicator of farmers' interest in soil fertility. From 1984 – 1988, on average 2.3 soil samples per farm have been analysed by BLGG. Almost 20 years later, from 2000 – 2004, on average only 1.2 soil samples per farm have been taken (Chapter 4), suggesting a decreasing interest in soil fertility over time. Yet, the number of soil samples per acreage is still much higher in the Netherlands than in for example Brittany, New York State, and New Zealand (Chapter 4).

The number of soil samples increased again in 2005 - 2006 when N-fertilization on dairy farms became dependent on soil N test results, and in 2009 – 2010 when P-fertilization became dependent on soil P test results. Interestingly, the majority of the farmers choose to have a wider range of soil characteristics analysed then strictly necessary to comply with legislation, even though these are available only at a higher price. The results of these soil tests were appreciated by farmers; soil tests form an important ingredient for setting up a fertilization scheme (Chapter 7).

Another indication for the interest in soil fertility and plant nutrition is that, irrespective of soil type, an equal number of Dutch farmers expressed preference for a 'soil-based' P fertilization strategy as for a 'crop-based' fertilization strategy (Chapter 7). This contrasts with results obtained by Nesme et al. (2011); they found that most French farmers opted for a 'crop-based' fertilization strategy. Crop-based fertilization means an immediate return of investments; costs of fertilizer can be ascribed to the accompanying yield. Typical examples include foliar fertilization, split applications and top dressings of N fertilizer, and balanced fertilizer applications. Investments in a 'soil-based' fertilization strategy demands for investments that do not provide immediate returns in terms of higher yields or improved workability of the soil; rather, they are investments at a strategic, middle-long term level. For the individual farmer, this can be costly especially if he is not the land owner.

Soil fertility is also linked to food quality. Some have argued that soil fertility in western European countries has declined with respect to certain micronutrients because of one-sided fertilizer-N applications. This may indeed have resulted in lowered levels of (micro)nutrients in vegetables and as a consequence in a lower intake of micronutrients by humans (Mayer, 1997; Davis et al., 2004; White & Broadley, 2005; Benbrook et al., 2008). However, monitoring of (micro)nutrient contents in harvested crops is not done on a routine basis and it is difficult therefore to establish reliable relationships between soil fertility, fertilization practices, and (micro)nutrient contents in harvest crops in practice.

Nutrient management legislation

In 1984, the manure production in the Netherlands topped at 99.7 x 10^9 kg manure (CBS, 2013). So that year, ~50 ton of manure was available per hectare of agricultural land. At the same time, fertilizer-N usage peaked (Chapter 1). The oversupply of nutrients became problematic in many European Union countries, with the Netherlands as one of the 'leading' countries (Csathó & Radimszky, 2009). To curb over-fertilization, legislation was implemented.

In 1984, the Dutch government introduced milk and manure quotas per farm and P-based limits for manure application to land (Oenema, 2004). In 1991, the EU Nitrates Directive (De Clercq et al., 2001; www.europa.nl) was implemented to reduce water pollution caused by N from agricultural sources. To meet the targets of the EU Nitrates Directive, the Mineral Accounting System (MINAS) was introduced in the Netherlands, and in 2006 a system based on N and P application standards, differentiated by soil and crop type, was introduced (Figure 1). Manure production, fertilizer use, and thereby N and P surpluses decreased sharply since then. Between 1985 and 2010, the permissible N and P applications via animal manure decreased more than two-fold, and thereby organic matter input with manure.

On average about 2000 kg per ha per year of effective organic matter[1] is needed on arable land to maintain the soil organic matter content at a stable level (Kortleven, 1963; Wadman & De Haan, 1996). The organic matter supply via manure makes a significant contribution. As a result, decreasing manure inputs might cause farmers to worry about decreasing SOM levels (Chapter 7; Van Dam et al., 2006). However, I have not found evidence for a decline. Possibly, the decrease in organic matter input via animal manure has been compensated by alternative sources of organic matter (Chapter 7), such as compost, catch crops, especially after the growth of silage maize, green manure, and the return of straw to soil. Also, there are initiatives for reduced tillage (www.nietkerendegrondbewerking.nl) which reduces mineralization of organic matter. Manure separation in liquid and solid fractions may also provide options for more targeted application of organic matter (e.g. Schröder et al., 2009; Evers et al., 2010)

Although permissible P applications decreased sharply (Figure 1), results (Chapter 3, and 5) indicate that soil P levels remained relatively high during the first decades of legislation. Ultimately, plant available soil P levels will depend on the current total amount of P in the soil (the so-called quantity), and on the buffering processes which depend on soil type and other soil characteristics such as Fe, Al and Ca contents (e.g. Robbins et al., 1999; Siddique & Robbinson, 2003).

1 Effective organic matter is defined as the amount of organic matter that remains after one year of decomposition (Yang and Janssen, 2000)

Role of soil testing in future

Soil tests play a major role in farmers' decisions on fertilization and soil management as many farmers first consider the results of soil tests when making a fertilization plan (Chapter 7). The information provided by the soil test report has increased gradually over the years. However during the earlier days, analysing individual soil parameters was expensive and time consuming as different parameters required different test procedures and extractants that varied per soil type. Houba et al. (1990; 1994) and Van Erp (2002) proposed introducing the use of 0.01 M CaCl2 as single extractant to assess readily plant available nutrients and from 2004 onward this was gradually introduced in practice (e.g. Ros, 2011; Van Rotterdam – Los et al., 2009); Anonymous, 2013c). At about the same time, the Near Infra-Red (NIR) method was introduced to assess basic soil characteristics in a rapid and relatively low cost manner, including texture, SOM, CEC, exchangeable cations, etc. (e.g. Malley et al., 1999; Vedder et al., 2009; NEN-ISO 17184, 2013).

Nowadays, only 3 basic soil test methods (0.01 M $CaCl_2$, NIR, and P-Al) are used by modern soil laboratories in the Netherlands for assessing SOM, SOC, $CaCO_3$, clay, silt, sand, CEC, CEC saturation, N-total, S-total, P-Al, Ca-CEC, K-CEC, Mg-CEC, Na-CEC, pH, plant available Ca, P-$CaCl_2$, K-$CaCl_2$, Mg-$CaCl_2$, and Na-$CaCl_2$. Plant available micronutrients Mn, Cu, Co, Se, B, Zn, Si, Mo, Fe are also assessed using 0.01 M $CaCl_2$ as extractant, as are NO_3, NH_4-, DON-, and S-$CaCl_2$. All these soil fertility characteristics enable farmers to monitor and further improve soil fertility and to optimize yield and crop quality. However, these soil fertility indices mainly reflect the soil chemical aspects of soil fertility. Therefore, many arable farmers lack information about biological and physical soil fertility characteristics (Chapter 7). In response, current developments now aim to provide information about biological and physical characteristics of the soil (e.g., Hanegraaf et al., 2005; Haneklaus et al., 2005; Edwards & Bater, 1992), partly using Mid Infra-Red (MIR) and NIR (Minasny et al., 2009; Terhoeven – Urselmans et al., 2007; Stenberg et al., 2010).

Currently, most fertilization recommendations are based on a single soil test. However, it has been suggested repeatedly that two or more soil tests may provide more insight into the temporal dynamics and availability of soil nutrients to plants (especially soil P), and the crop response to fertilization (e.g. Kuipers, 1951; Van der Paauw, 1971; Ehlert ***et al.*** , 2003; Quintero et al., 2003). The combination of P intensity (i.e. the amount of P that is readily available for plant uptake), P buffering capacity, and P quantity has been the subject of several studies (Figure 2) (e.g. Dalal & Hallsworth, 1976; Moody et al., 1988; Celardin, 2003; Ehlert et al., 2003; Van Rotterdam-Los, 2010). Most farmers (~80%) are positive about new research efforts dealing with (combinations of) soil tests that would give more insight and improved recommendations (Chapter 7). However, new insights from soil tests are not easily implemented into agricultural practice. In Chapter 6, I therefore suggest a novel, three-step schedule for introducing new soil tests: (1) establishing new promising soil tests, (2) creating regression models between the old and new soil tests, and (3) implementing and validating the new soil test stepwise by fertilization trials. In this way, the knowledge based on the old soil tests can be used until the new soil tests and their subsequent crop responses are validated sufficiently. This schedule was used in the Netherlands for introducing new P recommendations based on P quantity and P intensity tests (Chapter 6).

From 2004, the combination of P quantity (P-Al) and P intensity (P-$CaCl_2$) tests were introduced and reported to farmers (and their advisors), but the soil test Pw was also reported to farmers and used for deriving the P fertilisation recommendations. At the same time the "intensity-buffering capacity-quantity" concept was tested further in pot experiments and field trails (e.g. Bussink and Temminghoff, 2004; Bussink et al., 2007; Van Rotterdam et al., 2009). Results of these experiments were presented to the Committee for Fertilization of Grassland and Fodder Crops. Seven years after introducing the dual soil P test values (P-$CaCl_2$ and P-Al) to the farmers, in early 2011, the new concept was approved for maize (Anonymous, 2013c),. In the meantime, farmers and their advisors had become familiar with the new soil P test values so that the new P fertilization recommendation was a relatively small step. Subsequently, the new P recommendation for grassland was approved early 2012, and further field trials for arable crops – to validate the concept – were approved by the end of 2012 (by the Product Board (Productschap) Arable Farming). An advantage of multiple soil tests for P is the possibility of distinguishing between soil-based fertilization strategies (i.e. soil fertility, investments for the longer term) and crop-based fertilization strategies (plant nutrition, investments for a single crop season). The intensity, buffering capacity, and quantity concept can also be applied for other nutrients.

In conclusion, the number of soil tests and extractants for soil fertility characterization has been strongly reduced during the last decade, while the number of characteristics and information about soil fertility has strongly increased, giving farmers the possibility to further optimise their (fertilization) management. New scientific insights have been gradually implemented into agricultural practice.

Final considerations

Striving for maintenance or improvement of soil fertility without causing environmental problems has led to site-specific strategies in soil nutrient management (precision farming) in which nutrients are applied in variable rates to fit local requirements (e.g., Bah et al., 2012). Variable rate application based on soil tests (like in Denmark) is labour-intensive and new techniques for on-the-go and on-site monitoring of soil nutrient concentrations might be an opportunity for high density measurements at affordable costs. It would allow for an efficient mapping of nutrient variability to facilitate variable-rate nutrient application. On-the-go sensors such as electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurement concepts could all be used (Adamchuk et al., 2004).

From all this, the question arises whether soil tests, analysed routinely for farmers since 1928 will see their centenary. Numerous initiatives to test these on-the-go sensors have been conducted. For example, Tremblay et al. (2012) suggested fluorescence-based technologies for (within-season) N fertilization recommendations with the potential to be used remotely within the context of precision agriculture. Kweon & Maxton (2013) tested an on-the-go optical soil sensor with red- and near-infrared wavelength with an electrical conductivity sensor for SOM and CEC mapping. Dierke & Werban (2013) studied gamma-ray spectrometry for mapping of physical soil characteristics. Naderi-Boldaji et al. (2013) considered soil compaction with on-the-go sensors. Shen et al. (2013) used on-the-go NIR for SOM and clay monitoring. They all concluded that the methods need further research, mostly on fields with a different or more heterogeneous soil texture. It is therefore my expectation that soil sensors will not yet replace conventional soil tests in the coming years. On the contrary, more information about the heterogeneity of soils and yields will likely increase the interest in conventional soil testing. For example, when farmers or their advisors see differences in yield, they may like to check if there is a relation with soil chemical, physical, or biological characteristics. They may want to know if a (part of a) field can be managed in such a way that yield limiting factors are improved by management operations like liming, growing plant-nematodes resistant crop varieties, soil structure improvement, etc. In addition, to validate the sensor techniques, reference soil samples are necessary.

On the longer term, on-the-go soil sensor techniques likely will replace conventional soil testing, and facilitate the decision-making process. New soil sensor data, together with crop growth, fertilization, crop protection, weather data, etc. collected at different levels of resolution (time and space), and together with historical data could all be integrated in decision support systems. For an individual farmer, the advantages of sensor techniques with data assessment should be promoted by showing that investments in such systems are an investment that will pay off through improved yields within a matter of years.

Overall main conclusions

- SOM content of agricultural land on mineral soils in the Netherlands remained on average stable at a relatively high level compared to soils of agricultural land in other countries. SOM tended to increase in soils with relatively low levels (< 14%) and tended to decrease on soils with relatively high levels (≥14%). The SOM content of peat land area has decreased during the last decades to centuries, mainly due to increased drainage.
- Soil P status on arable land increased from the agronomical classification (ample) 'sufficient' to (fairly) 'high', while soil P status on grassland remained within the optimal range during the last few decades.
- Legislative limits and measures on N and P applications have not yet shown up in measurable effects on mean SOM and/or soil P status.
- Almost all herbage characteristics are within or just above their optimal agronomical range.
- Farmers indicate that soil tests form an important (starting) ingredient for making a fertilization scheme; they regard soil tests more important than their own knowledge and recommendations by advisors. On the soil test report, soil P status is considered most important, before K status and SOM content.
- Despite the appreciation for soil test information, about 70% of arable farmers question the analytical value of the soil P test and aim at a soil P status above the agronomical optimal range.
- Implementing new insights related to soil tests proves hard in practice. Therefore, I have suggested a novel, three-step schedule for introducing new soil tests into practice, in which knowledge based on the old soil tests can be used until the new soil tests and their subsequent crop responses are validated sufficiently.
- Although the number of soil parameters that can be analysed has increased greatly, there is still demand for new parameters, especially those reflecting biological and physical characteristics of the soil.

Recommendations

In this research I had to assume that the BLGG database that I used was representative for the Netherlands as a whole (a.o. Chapter 2). Given the importance of accurate information about spatial variations in soil fertility at different spatial scales, setting up a systematic sampling procedure is recommended (Vermeulen & Fey, 1957; Brus et al., 2011), in particular for SOM and P status. In that way temporal changes in soil fertility can be monitored with more certainty.

Minimum values of SOM per soil type or texture class should be established, taking the several functions of SOM (like soil workability, cation binding, water holding capacity and disease suppression) into consideration.

Farmers' interest in improved allotment of P, their uncertainty about actual plant available P (Chapter 7), and the measured large variations of plant available P (P-intensity) within soil Pw or P-Al test (Reijneveld & Oenema, 2012b), seem the right ingredients to further investigate the use of multiple soil P tests for legislative purposes (Table 1).

Table 1 Percentage (%) of soil classified according to Dutch P legislation and suggestion for classification according to the quantity, intensity concept, including percentages for a) grassland (Reijneveld & Oenema, 2012b), and b) open cultivations; soil data from 2009.

Table 1a

P-intensity	P-quantity (P-Al, mg P_2O_5 100 g^{-1})			
(P-$CaCl_2$, mg P kg^{-1})	Low (<27)	Neutral (27 - 50)	High (>50)	Total
Low, < 1	16	14	4	34
Neutral, 1 - 2	5	17	2	24
High, > 2	3	27	11	41
Total	24	58	17	100

Table 1b

P-intensity	P-quantity (P-Al, mg P_2O_5 100 g^{-1})			
(P-$CaCl_2$, mg P kg^{-1})	Low (<27)	Neutral (27 - 50)	High (>50)	Total
Low, < 1	6	2	2	10
Neutral, 1 - 2	8	15	14	37
High, > 2	2	11	40	53
Total	16	28	56	100
	Current Pw (mg P_2O_5 L^{-1}) classification			
	Low (<36)	Neutral (36 - 55)	High (>55)	
Total	22	42	36	100

Multi-nutrient soil test methods and techniques like NIR make it possible to analyse many soil characteristics in one soil sample, fast and cost efficiently. For example, in one soil sample several soil P fractions (like P-total, P binding capacity, P saturation, and P intensity; Figure 2) can be measured. These new characteristics can be used to better align soil- and crop-based fertilization recommendations with environmental limits and goals.

Soil P status on grassland remained remarkably stable during the last decades (Chapter 3). A possible explanation was gradual uploading of the subsoil. However, soil status (a.o. binding capacity) and development of soil characteristics in the subsoil layer is largely unknown to farmers as well as for researchers. Fertilization recommendations and insights into the risk for environmental problems can both be improved if the subsoil layer (of grassland and open cultivations) would be analysed together with the top layer.

On farms, geo-referenced soil fertility characteristics should be combined with information about feed composition, manure composition and/or crop characteristics to be able to make fertilization recommendations farm-, field- and crop-specific (Chapter 5).

Farmers are interested in biological soil characteristics (Chapter 7) and there are several initiatives to measure biological fertility on a cost-efficient, quick and routine basis. How to integrate knowledge of soil chemical, physical and biological characteristics and make practical recommendations for farmers is yet largely unknown and should be further investigated.

Summaries

SUMMARY

SAMENVATTING

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Summary

Introduction

On fertile soils, high-yielding crop production systems can be built which are indispensable both for profitable farming and for feeding the steadily increasing world population. There are three main, partially interacting components of soil fertility: physical, chemical, and biological, together determining soil fertility. Worldwide, cases of low and declining soil fertility have been reported, resulting in soil degradation and subsequent declining yields. On the other hand, attempts to increase soil fertility and crop yields by applying manures and fertilizers may result in environmentally unwanted site-effects such as nutrient losses to air and waters, contributing to, a.o., water pollution, biodiversity loss, and possibly climate change.

This PhD thesis deals with soil fertility in the Netherlands. Agriculture in the Netherlands is, expressed per unit of area, one of the most productive in the world, which can be ascribed in part to the high soil fertility and favourable climatic conditions. Part of this soil fertility was inherited from the sea and the river delta made up by the Rhine, Meuse and Scheldt. For the other part , in the eastern and southern parts of the country, soil fertility is man-made, as soils here originally were poor sandy soils. The study of soil fertility in the Netherlands is of interest because of its intensive agriculture and more recently its governmental regulations to limit manure and fertilizer applications, so as to reduce negative environmental effects of intensive agriculture. This thesis aims to increase the understanding of spatial variations and changes over time in soil fertility of farmers' fields in the Netherlands during the last century. More specifically, the thesis addresses the following research questions:

- Which changes have taken place in soil organic matter contents (Chapter 2), and soil phosphorus contents (Chapter 3) of agricultural land during the 20th century, as function of land use, soil type and region?
- Will mean soil P status develop towards the optimal agricultural range, with a small standard deviation when virgin soil is cultivated with high craftsmanship? (Chapter 4)
- How did herbage quality and cattle manure composition respond to changes in mean soil fertility in dairy farming? (Chapter 5)
- What are farmers' perceptions and concerns regarding soil fertility? (Chapter 7)
- How to improve the usability of fertilization recommendations, using new knowledge? (Chapter 6)

Soil fertility: past & present

The Netherlands was inhabited from ~5000 BC on elevated areas in the southern part of the country. Expansion to other regions was slow, probably because of the risk of temporarily flooding, but from the 10th century AD onwards, large parts of the coastal provinces were reclaimed from the sea and lakes by establishing polders. In the middle ages, wheat production was 1500 kg ha^{-1} on the calcareous clayey soils in Zealand, twice the yield from the loess and sandy areas around Maastricht (province Limburg). About 400 years later, at the beginning of the 20th century, average yield had increased to 2200 kg ha^{-1}. In the last century, this quadrupled to almost 9000 kg ha^{-1}. Higher production levels could be realised by plant breeding, improved irrigation, crop protection, and improvements in soil fertility and plant nutrition from the second half of the 19th century onwards. In this period, the very first field experiments were performed and soil testing started at research institutes (Chapter 1). In 1927, an independent laboratory for routine soil tests (BLGG) was established in the Netherlands. Soil samples were analysed at farmers' request and results documented in reports to farmers only. Overviews of soil characteristics (means, median, maximum and minimum values) were made incidentally. From 1984 onwards, results were compiled and archived in an electric data base. Currently, the data base consists of > 5 million records of soil analyses. The number of soil samples per unit of surface is much higher in the Netherlands than in many other countries. Farmers state they value the soil tests and recommendation and use it for the fertilization schemes. Since fertilization recommendations have been developed to optimise production, compliance with these recommendations would therefore have resulted in soil fertility characteristics within the optimal ranges (Chapters 2, 3, 4, and 5). In addition, since recommendations for grasslands also consider the element of herbage quality, compliance to fertilization recommendations would be expected to have also resulted in optimal levels of essential elements in harvested herbage (Chapter 5).

Soil organic matter

Soil organic matter (SOM) is generally regarded the most important soil fertility characteristic, embracing chemical, physical and biological fertility aspects. There are worldwide reports about declining SOM content, which is ascribed to changes in land use, increased soil cultivation and, possibly, climate change. Dutch farmers have concerns that a decrease in SOM compromises the production capacity of the soil. However, I found that mean SOM content remained stable or even tended to increase in the last decades for mineral soils (Chapter 2). For these soils, average SOM content is 8.1% for grassland (0 – 10 cm; reference years 2007 - 2008) and 4.3% for arable land (0 – 25 cm) (reference years 2004), well above the sometimes believed 'critical' content of 3.4% SOM. Interestingly, regions with high SOM contents tended to have decline SOM contents while those low in SOM remained stable or increased (Chapters 2 and 5). The results on SOM evolution in time are in contrast with inventories in England, Wales, Flanders, Brittany (France), Norway, Bavaria, and Finland where a general decline was reported (yearly decline of about 1% of the initial value). This difference may reflect the relative large external organic inputs to agricultural soils in the Netherlands, mainly in the form of animal manure (approx. 40% of total input), and crop residues from grassland and arable crops. Despite the relatively constant and high mean SOM status in the Netherlands, many farmers placed SOM first on the list of 'future worrisome' soil fertility aspects, independent of region/soil type (Chapter 7). Farmers indicated that they would like to see more information about SOM quality. Concerns about SOM are likely related also to current limits on manure and fertilizer N and P use, thereby limiting the input of effective C from external sources. Thus, current farmer's worries seem to be based on future worries; indeed, it cannot be excluded that SOM levels will decline in future under continued intensive soil cultivation and further reduced organic matter inputs.

Soil phosphorus

In the 20th century, cumulative mean phosphorus (P) surpluses were ~4500 kg P_2O_5 ha^{-1}. With that input, average soil P status on arable land (soil Pw test) increased from the agronomical classification '(ample) sufficient' to '(fairly) high' during the period 1971 – 2004. Remarkably, soil P status on grassland (P-Al) remained within the optimal range in almost 4 decades (Chapter 3). Probably, some P has accumulated in the subsoil. Legislation (since 1984) has not yet had a measurable, significant effect on soil P-Al and soil Pw status, despite the drastic decrease in P application rates. In general, regions with high livestock density have high soil P status. Soil P status increased in the order bulb flower land < grassland < arable land < maize land < horticulture, and in the order loess < clay < peat < sand soils. The spatial variation in soil P test values observed reflect that P use is primarily related to the market value of the grown crops as well as to the regional availability of animal manure rather than to P fertilization recommendations. These differences between land use and regions had already been reported at the end of the 19th century and again in the 1930s.

For testing the hypothesis that soil P status will develop towards the optimal agricultural range when complying with fertilization recommendations, I chose the Northeast Polder as study area (Chapter 4). The Northeast Polder was reclaimed from the sea in 1942, has one major soil type (calcareous loam), well-educated farmers, one dominant land use (arable farming) and little pressure to use animal manure. In this highly productive polder, soil P(w) values increased steadily and significantly from the agronomical range ‘low’ in the 1970s to ‘ample sufficient’ in 2004. However, 28% of the fields had above optimal P status in the last 4 study years. Results of a questionnaire suggested that risk avoidance is a decisive factor for pursuing a soil P status above the agronomical optimal range, since 45% of the farmers appear to aim to reach that level, and >70% of the farmers indicated that they are uncertain whether the obtained increase in soil P(w) status is actually plant available P.

Relationships between soil fertility indices and the composition of herbage and cattle slurry were studied on dairy farms in three characteristic regions and in the Netherlands as a whole (Chapter 5). Here, I found that mineral contents of herbage were almost all within or just above their optimal agronomical ranges. Mean soil fertility characteristics (including soil P status) were within or just above the agronomical optimal range during the last decades. Effect of legislative measures have not (yet) resulted in decreasing P-status of soil and/or in decreasing P contents of herbage and manure. However, herbage crude protein content did decrease in the study period (1996 – 2009; Chapter 5), which is likely an effect of decreasing N applications via manure and fertilizers due to legislative measures.

Other soil characteristics

Mean pH values in the Netherlands were within or just above the optimal ranges. For grassland, soil pH remained stable in the last decades, but with regional differences; dairy farmers on sandy soils increased the soil pH status in the last decades (1977 – 2000) (Chapter 5). However, although average soil pH may be within the agronomical optimal ranges, there are important exceptions, on 75% of the analysed maize fields on sandy soils, soil pH is below optimal levels. Mean soil K status increased on many soils in the Netherlands, but the increase slowed down from about 2000, probably because of decreased manure and fertilizer applications.

In a questionnaire (Chapter 7) many farmers indicated that they first of all consider the results of soil tests when making a fertilization plan. However they also question the fertilization recommendations, and notably aim at higher levels of soil P fertility than recommended. Farmers also endorse improved allotment of P via fertilizer and manure. Possible solutions include more refined P fertilization recommendations and improved communication to farmers and their advisers.

Soil fertility: future

Implementing new insights about soil tests in agricultural practice is not easy because replacing existing soil tests would imply a very significant effort in terms of evaluating the new ones in practice. Therefore, a novel, three-step schedule for introducing more trustworthy soil tests was suggested (Chapter 6): (i) establishing new promising soil tests, (ii) creating regression models between the old and new soil tests, and (iii) implementing the new soil test stepwise by fertilization trials. In this way, knowledge based on the old soil tests can be used until the new soil tests and their subsequent crop responses are validated sufficiently. This stepwise introduction was successfully used for P recommendations and can be applied for other nutrients.

The importance of soil fertility for high quality feed production was also demonstrated in this research. At farm level the element composition of herbage reflected the soil fertility status; the contents of S, P, K, Na, Mg, and Ca in the herbage were all significantly influenced by soil fertility characteristic (Chapter 5). The challenge is to further link soil fertility indices at field level to crop yield and crop quality.

Farmers endorse the importance of soil fertility and have concerns regarding the future of soil fertility (Chapter 7). In near future, more attention should be paid to monitoring soil structure and soil life, as these parameters are not determined routinely yet. The increasing amount of soil chemical characteristics and the interest in soil physical and soil biological characteristics give farmers in the Netherlands a chance to monitor and to further improve soil fertility and to optimize yield and crop quality. Expect for N and P, all these soil characteristics can be influenced without legislative restrictions.

Soil testing will continue to be an important tool for monitoring and improving soil fertility and soil management, and will likely not be replaced by on-the-go sensors in the coming years. On-the-go sensors provide visual information about the heterogeneity of soils and of yield, and may on the short term contribute to an increase in the interest in conventional soil testing, also for verification purposes. On the longer term, on-the-go soil sensor techniques will replace conventional soil testing. New soil sensor data, together with crop growth, fertilization, crop protection, weather data, etc. collected at different resolutions, scales, time, and together with historical data could all be integrated in decision support systems. To achieve this, multiple layers of information need to be analysed and assessed. Evidently, the advantages of sensor techniques and data assessment in terms of increases in yield and/or quality must outweigh the cost related to the investments in sensor technology and data assessment.

Samenvatting

Inleiding

Hoge gewasopbrengsten zijn van belang om de groeiende wereldbevolking van voedsel te kunnen voorzien. Hoge gewasopbrengsten per hectare zijn ook van belang voor een rendabele bedrijfsvoering. Deze hoge opbrengsten kunnen eenvoudiger worden gerealiseerd op gronden met hoge bodemvruchtbaarheid dan op gronden met lage bodemvruchtbaarheid. Bij gronden met lage bodemvruchtbaarheid is het zelfs bij hoge bemestingsniveaus nauwelijks of niet mogelijk om de maximale opbrengst per hectare te realiseren. Bodemvruchtbaarheid kan dan ook worden gedefinieerd als 'het opbrengend vermogen van de bodem' of het 'nutriëntenleverend vermogen van een bodem'.

Bodemvruchtbaarheid bestaat uit drie componenten: fysische, chemische en biologische bodemvruchtbaarheid. Door bemesting, bekalking en grondverbetering kan de bodemvruchtbaarheid worden verbeterd. Teveel bemesting brengt echter problemen met zich mee: een toename van nutriëntenverliezen naar het milieu door vervluchtiging en af- of uitspoeling. Hierdoor kan water vervuilen, neemt de biodiversiteit af en kan het uiteindelijk effecten op het klimaat hebben.

Mijn promotieonderzoek gaat over de bodemvruchtbaarheid in Nederland. De Nederlandse landbouw is een van de meest productieve in de wereld. Samen met Frankrijk staat Nederland op de tweede plaats van grootste landbouwexporteurs (bloemen, vlees, fruit, groenten, bier, melkproducten, zetmeel, zaad) in de wereld; alleen de Verenigde Staten gaat ons voor. De gewasproducties per hectare behoren tot de hoogste in de wereld. Naast onder andere gewasveredeling, gebruik van gewasbeschermingsmiddelen, drainage en gunstige weersomstandigheden speelt de hoge bodemvruchtbaarheid en bemesting een doorslaggevende rol voor deze hoge producties. De hoge bodemvruchtbaarheid is deels te danken aan de zee en de rivieren die vruchtbare klei hebben afgezet in het noorden, midden en westen van Nederland. De zandgronden in het oosten en zuiden van Nederland waren van oorsprong arm maar zijn door jarenlange bemesting vruchtbaar gemaakt.

In de jaren 70 van de vorige eeuw werd het negatieve effect van een te hoge aanvoer van mest steeds meer onderkend en dat resulteerde – vanaf 1984 – in mestwetgeving. In de jaren daarna zou deze wetgeving geleidelijk aan stringenter worden. Het is de vraag of de hoge bodemvruchtbaarheid behouden kan worden door deze recente wetgeving. Met mijn onderzoek heb ik getracht meer inzicht te krijgen in de bodemvruchtbaarheid van landbouwpercelen in Nederland. Het accent lag daarbij op organische stof (OS) en fosfaat

(P). OS is een indicator van zowel fysische, chemische, als biologische bodemvruchtbaarheid. Fosfaat is essentieel voor de groei en ontwikkeling van planten; het is een onderdeel van vele celonderdelen (waaronder DNA) en het speelt een belangrijke rol in de energietransport in planten.

De volgende onderzoeksvragen werden behandeld:

- Hoe heeft het OS-gehalte (Hfdst. 2) en de P-toestand (P; Hfdst. 3) van landbouwgronden zich ontwikkeld in de 20ste eeuw?
- Neemt de P-toestand van landbouwgronden op akkerbouwbedrijven toe tot de landbouwkundige klasse “optimaal” om daarna stabiel te blijven (Hfdst. 4)?
- Hoe is de ruwvoerkwaliteit en de mestsamenstelling op melkveebedrijven beïnvloed door (veranderingen in) bodemvruchtbaarheid (Hfdst. 5)?
- Hoe zien boeren bodemvruchtbaarheid en maken ze zich hierover zorgen (Hfdst. 7)?
- Hoe kunnen nieuwe inzichten rondom bodem en bemesting worden geïmplementeerd (Hfdst. 6)?

Hieronder licht ik deze vragen verder toe en laat de belangrijkste conclusies de revue passeren.

Bodemvruchtbaarheid: verleden tot heden

Vanaf ongeveer 5000 jaar v.C. werd Nederland bewoond; eerst alleen op hoger geleden gebieden in het zuiden van het land, want in andere gebieden bleef het risico op overstromingen lange tijd te groot. Pas 6000 jaar later (10de eeuw n.C.) werden ook de kustprovincies steeds meer gekoloniseerd en werden dijken aangelegd en polders gemaakt. Op deze vruchtbare zeekleigronden werd in de middeleeuwen 1500 kg tarwe per hectare geoogst (Zeeland), twee keer zoveel als op armere zand- en lössgronden rond Maastricht (Limburg). Zo’n 400 jaar later, aan het begin van de 20ste eeuw, werden opbrengsten van 2200 kg per hectare gerealiseerd. Aan het begin van de 21ste eeuw waren de graanopbrengsten verviervoudigd, tot bijna 9000 kg per hectare. Deze hogere producties konden worden gerealiseerd omdat nieuwe inzichten en technieken resulteerden in betere drainage, gewassen, gewasbescherming en bodemvruchtbaarheid en bemesting. Zo werden vanaf de tweede helft van de 19de eeuw veldexperimenten (bemestingsproeven) gestart en werd grondonderzoek gedaan om de bodemvruchtbaarheid van de grond te bepalen (Hfdst 1). In 1927 werd een afzonderlijk laboratorium voor grondonderzoek (BLGG) in het leven geroepen. Vanaf het begin werd het grondonderzoek uitgevoerd op aanvraag van de boer. De resultaten van het onderzoek werden toegelicht door de landbouwvoorlichting. Eerst werd alleen de pH geanalyseerd, maar al snel volgden een bepaling voor plant-beschikbare P (1930), P-bodemvoorraad (1933) (Hfdst. 3) en kalium (1933). Al snel werden overzichten gemaakt van deze bodemkengetallen, veelal per grondsoort of per regio. Vanaf 1984 zijn de gegevens van grondonderzoek (en ook van gewas en mest) gearchiveerd in digitale databases. Sinds 1984 zijn meer dan 5 miljoen resultaten van grondonderzoek van landbouwgronden op deze wijze vastgelegd. Het aantal grondmonsters dat per hectare wordt geanalyseerd, is in Nederland hoger dan in de meeste andere landen. De resultaten van het grondonderzoek worden door boeren benut voor het maken van bemestingsplannen. Op basis van de resultaten van grondonderzoek en vele veldproeven werden voor diverse sectoren bemestingsadviezen vastgesteld. Zo is er een adviesbasis voor grasland en voedergewassen, voor akkerbouw en voor bloembollen. Het volgen van de gegeven bemestingsrichtlijnen resulteert volgens de theorie in een optimale bodemvruchtbaarheid; bodemkengetallen ontwikkelen zich richting het landbouwkundig optimale traject (Hfdst. 3, 4 en 5). Aangezien de bemestingsadviezen bij grasland ook rekening houden met de gewenste mineralentoestand in ruwvoer, is het de verwachting dat het volgen van de adviezen ook resulteert in optimale mineralengehaltes in gras (Hfdst. 5).

Organische stof

Organische stof (OS) is een van de belangrijkste kengetallen van bodemvruchtbaarheids, omdat het een belangrijke rol speelt bij zowel fysische, chemische, als biologische bodemvruchtbaarheid. Een afname van het OS-gehalte wordt op veel plaatsen in de wereld waargenomen, vooral na ontbossing en na het omploegen van grasland. Ook wordt deze afname toegeschreven aan veranderde grondbewerking (o.a. dieper ploegen), minder aanvoer van organisch materiaal (mest) en klimaatveranderingen. Veel boeren, voorlichters en landbouworganisaties maken zich zorgen dat het OS-gehalte van bodems in Nederland ook afneemt en dat daardoor het opbrengend vermogen van landbouwgrond daalt. In mijn onderzoek vond ik dat het gemiddelde OS-gehalte van minerale gronden in Nederland niet afnam (onderzocht tot en met 2004 voor bouwland en tot met 2009 voor grasland). Grasland bevat gemiddeld 8,1% OS (0 – 10 cm) en bouwland 4,3% (0 – 25 cm). Dat is ruim boven het in de literatuur wel genoemde kritische niveau van 3,4%. Regionale verschillen in het verloop van het OS-gehalte waren relatief groot. In regio's met een relatief hoog OS-gehalte werd geconstateerd dat het OS-gehalte daalde, terwijl in regio's met een relatief laag OS-gehalte dit stabiel bleef of zelfs wat toenam (Hfdst. 2 en 5). Deze resultaten verschillen met die uit Engeland, Wales, Vlaanderen, Bretagne (Frankrijk), Noorwegen, Beieren en Finland; in deze landen werd een gemiddelde afname geconstateerd (grofweg zo'n 1% afname per jaar van het oorspronkelijke OS-gehalte). Het verschil wordt waarschijnlijk veroorzaakt door de grotere aanvoer van organisch materiaal in Nederland in de vorm van dierlijke mest en gewasresten. Ondanks dat het OS-gehalte gemiddeld hoog en stabiel was, maken boeren zich toch zorgen over het OS-gehalte; ze zetten het – onafhankelijk van regio of grondsoort – bovenaan de lijst met 'zorgen aangaande de toekomst van bodemvruchtbaarheid' (Hfdst. 7). Boeren geven ook aan dat ze meer informatie over de kwaliteit van organische stof zouden waarderen. De zorgen over het OS-gehalte van de bodem zijn mogelijk deels een gevolg van de beperkingen die gelden voor het gebruik van dierlijke mest (mestwetgeving), waardoor er minder organische stof via mest kan worden aangevoerd. Ondanks dat er in de onderzochte periode geen effecten werden gevonden, is een daling van het OS-gehalte in de toekomst niet uit te sluiten. Het OS–gehalte van Nederlandse landbouwgronden moet daarom worden gemonitord gezien het belang hiervan voor de landbouw.

Fosfaattoestand

In de 20ste eeuw was de gemiddelde aanvoer van fosfaat (P) op landbouwgronden veel ruimer dan de gemiddelde afvoer met het geoogste gewas; in totaal werd gemiddeld circa 4500 kg P_2O_5 per hectare meer aangevoerd dan afgevoerd. Dit had onder andere effect op de P-toestand van de bodem; zo steeg de gemiddelde P-toestand van bouwland (gemeten met de Pw-methode) van "ruim voldoende" tot "(vrij) hoog" in de periode 1971 tot 2004 (Hfdst. 3 en 4). Op grasland bleef de P-toestand (gemeten met de P-Al-methode) opmerkelijk stabiel gedurende deze periode (Hfdst. 3 en 5). Waarschijnlijk heeft een groot deel van de netto aangevoerde P zich opgehoopt in diepere bodemlagen. Daarnaast is een deel vastgelegd in verbindingen die niet langer plant-beschikbaar zijn (bijvoorbeeld door associaties met ijzer- en aluminium-oxi-hydroxiden en/of neerslagen van calcium-hydroxyapathieten). Een deel van deze verbindingen zal niet worden gemeten met de gebruikte meetmethodes voor de bepaling van de P-toestand van de bodem.

De afname van de P-bemesting sinds 1984 heeft niet geleid tot een duidelijke verandering in de tijd van de gemiddelde Pw- en P-Al (Hfdst. 3, 4 en 5). De gemiddelde P-toestand verschilt met het landgebruik: bollenteelt < grasland < bouwland < maïsland < vollegrond, en met de grondsoort: löss < klei < veen < zand. De marktwaarde van gewassen en ook het aanbod van mest in een regio bepalen dus voor een groot deel de P-toestand van de bodem. Het bemestingsadvies (met daarbij een richtlijn voor de optimale P-toestand) lijkt in deze situaties niet te zijn opgevolgd. Het effect van het type grondgebruik (teelt) op de P-toestand van de bodem werd al aan het einde van de 19de eeuw geconstateerd.

Ik concentreerde me verder op de rol van het bemestingsadvies in de praktijk, met het idee dat de P-toestand van de bodem zich zou moeten ontwikkelen richting het landbouwkundig optimale traject als er i) geen groot mestaanbod is in de direct omgeving, ii) eenzelfde grondsoort en landgebruik aanwezig zijn, en iii) er geen lange historie van variatie in landgebruik en bemesting aanwezig zou zijn. De Noordoostpolder (NOP), ingepolderd in 1942, past bij dit profiel (Hfdst. 4). In dit akkerbouwgebied worden op kalkrijke leem hoge landbouwopbrengsten gerealiseerd. De eerste generatie boeren die hier mochten starten, waren bovendien geselecteerd op vakmanschap. De P-toestand van de landbouwgronden in de NOP nam inderdaad toe van gemiddeld "laag" in de jaren 70 van de vorige eeuw tot "ruim voldoende" in 2004, maar het aandeel percelen met een P-toestand boven het optimale traject nam ook sterk toe van ongeveer 0% (1971 – 1975) tot 28% in de laatste 4 jaar (2000 – 2004). In een schriftelijke enquête vroeg ik de akkerbouwers om hun beweegredenen over de P-toestand en het P –bemestingsadvies. Daaruit bleek dat 45% van de akkerbouwers streefde naar een P-toestand die (net) boven het landbouwkundige optimum lag en 70% van de boeren zegt dat de P-toestand is toegenomen, maar dat ze zich afvragen of de gemeten P ook daadwerkelijk beschikbaar is voor het gewas. Een hogere P-toestand werd overigens jarenlang beschouwd als "goede landbouwpraktijk". Het streven naar een hogere P-toestand kan vanuit landbouwkundig oogpunt geen kwaad, want zelfs bij een zeer hoge P-toestand is er geen schade aan gewaskwaliteit of opbrengst. Pas in de jaren '70 van de vorige eeuw kwamen er kritische geluiden of een hoge P-toestand een economisch rendabele strategie is en milieukundig verantwoord is. Het bemestingsadvies van grasland houdt ook rekening met de gewenste hoeveelheid mineralen in gras. Het opvolgen van het bemestingsadvies zou op veehouderijbedrijven dus betekenen dat zowel de bodemkengetallen als de graskwaliteit (mineralen in graskuil) in het landbouwkundig optimale traject liggen. Voor drie karakteristieke veehouderijgebieden (Groene Hart, Rivierengebied, Achterhoek) en voor Nederland als geheel is dit getest (Hfdst. 5). Het mineralengehalte in graskuilen lag overal in of net boven het optimale traject en ook de bodemkengetallen lagen veelal in het landbouwkundig optimale traject. Mestwetgeving heeft tot nu toe geen duidelijk effect gehad op bodemkengetallen en graskuilkengetallen, maar met een belangrijke uitzondering; het ruw-eiwitgehalte is significant gedaald in de periode 1996 tot 2009. Dit is ongetwijfeld een effect van de door de wetgeving ingegeven vermindering van de totale N-gift via dierlijke mest en kunstmest.

Andere bodemkengetallen

De zuurgraad (pH) van de bodem wordt vaak als een van de belangrijkste bodemvruchtbaarheidskengetallen gezien, samen met het OS-gehalte en de P-toestand. De gemiddelde pH van de bovengrond van landbouwbodems ligt in Nederland veelal binnen of net boven het optimale traject. Op grasland bleef de pH stabiel gedurende de laatste decennia (Hfdst. 5). Wel werden grote regionale verschillen waargenomen. Zo verbeterden melkveehouders op zandgrond de pH van hun percelen in de periode 1970 tot 2000 (Hfdst. 5). Op 75% van de geanalyseerde maïspercelen bleek de pH daarentegen te laag te zijn.

Kalium (K) is ook een belangrijke voedingsstof voor gewassen. De K-toestand van de bodem nam toe in de periode 1970 tot ongeveer 2000. Daarna steeg de K-toestand niet verder, waarschijnlijk als gevolg van verminderde mestgiften ten gevolge van het mestbeleid.

In hoofdstuk 7 is via enquêtes onderzocht hoe boeren de bemestingsadviezen, grondonderzoek en bodemvruchtbaarheid beleven. Uit de ingevulde enquêtes (20% van de boeren vulde de enquête in) blijkt dat ze grondonderzoek en bemestingsadviezen waarderen, en benutten voor het maken van een bemestingsplan. De deelnemers aan de enquête geven echter ook aan (net als de boeren in de Noordoostpolder, Hfdst. 4) dat ze twijfels hebben over het bemestingsadvies foor fosfaat (P). Veel boeren streven naar een hogere P-toestand dan het landbouwkundig optimale niveau. Gezien het grote belang van goed omgaan met fosfaat (de wereldwijde voorraden aan ruwfosfaat die gebruikt worden voor fosfaatkunstmest slinken snel, en fosfaatverliezen naar het oppervlaktewater dragen bij aan eutrofiëring en afname van de biodiversiteit) lijkt het van groot belang om verbeterde bemestingsadviezen te introduceren in de landbouwpraktijk. Boeren geven ook aan dat ze initiatieven om kennis uit (wetenschappelijk) onderzoek te introduceren in de landbouwpraktijk toejuichen.

Bodemvruchtbaarheid: Toekomst

Er is de 20ste eeuw veel onderzoek gedaan naar bodemvruchtbaarheid en bemesting, maar elk land heeft dat wel op eigen wijze gedaan, vooral voor fosfaat (P). Dat heeft er toe geleid dat er alleen al in Europa legio methoden zijn om de P-toestand te bepalen. Sommige methoden zijn redelijk wijd verbreid, zoals de P-Olsen-methode die in Denemarken, Griekenland, Nieuw-Zeeland en de Verenigde Staten wordt gebruikt en de P-Al-methode die in Nederland (voor grasland) en bijvoorbeeld in België, Zweden en Hongarije wordt gebruikt. Andere methoden zijn veel minder wijd verbreid, zoals de Pw-methode, die alleen voor open teelten in Nederland wordt gebruikt

Het P-bemestingsadvies is gewoonlijk gebaseerd op één bepalingsmethode. Een combinatie van twee of meer bepalingsmethoden voor P geeft echter meer inzicht in de relevante bodemprocessen, en leidt tot een verbeterd bemestingsadvies. Hierbij kan dan onderscheid gemaakt worden tussen de op korte termijn plant-beschikbare P-voorraad in de bodem (‘P-intensiteit’), hoe goed de bodem in staat is de plant-beschikbare P-voorraad op peil te houden (‘P-buffering’) en hoe groot de bodemvoorraad is waaruit P gebufferd kan worden (‘P-kwantiteit’). Dit concept (intensiteit, buffering en kwantiteit) levert naar verwachting een betrouwbaarder advies op dan een advies gebaseerd op één bepalingsmethode. Bij verandering van bepalingsmethodiek moet ook de interpretatie, het bemestingsadvies, aangepast worden. Dit belemmert innovaties naar verbeterde bepalingsmethodieken, omdat bemestingsadviezen gebaseerd zijn op talloze bemestingsproeven en daaruit afgeleide relaties tussen P-toestand van de bodem en de reactie van het gewas op P-bemesting.

Om deze problematiek van implementatie van nieuwe bepalingsmethodieken in (verbeterd) bemestingsadvies op te lossen stel ik een geleidelijke overgang voor in drie stappen: i) het vaststellen van nieuwe, verbeterde analysemethoden, ii) het creëren van statistische verbanden tussen de oude en de nieuwe analysemethoden en iii) het stapsgewijs implementeren en valideren van nieuwe adviezen. Op deze manier kan alle kennis die gebaseerd is op de "oude" methode benut worden totdat de nieuwe kengetallen voldoende zijn gevalideerd (veldproeven, modellen). Dit systeem is met succes toegepast voor bouwland; sinds 2004 werd bij open teelten naast Pw ook P-$CaCl_2$ (als intensiteitsparameter) en P-Al (als kwantiteitsparameter) weergegeven. Bemestingsadviezen werden verder gevalideerd en zeven jaar na het introduceren van nieuwe P-bodemkengetallen werd het bijhorende bemestingsadvies "officieel" goedgekeurd. In de tussentijd was de landbouwpraktijk gewend geraakt aan de nieuwe inzichten. Dit concept kan nog verder worden verbeterd door de bufferingscapaciteit van de bodem beter in te schatten (via o.a. Ca-, Fe- en Al-bepalingen), maar het kan ook voor andere nutriënten worden benut. Verbeterde adviezen kunnen resulteren in meer verantwoord gebruik van hulpbronnen, maar zullen blijvend moeten worden ondersteund door voorlichters zodat de meerwaarde helder wordt en het vertrouwen groeit.

Verder onderzoek om bodemkengetallen op perceelsniveau te koppelen aan gewaskwaliteit en aan opbrengend vermogen van een perceel wordt aanbevolen. Boeren geven duidelijk aan dat ze bodemvruchtbaarheid belangrijk vinden en dat ze zich zorgen maken over bodemvruchtbaarheid in de toekomst (Hfdst. 7). Met name een mogelijke achteruitgang in OS-gehalte en in bodemstructuur wordt als zorgelijk ervaren. Bovendien zouden ze meer informatie willen ontvangen over de kwaliteit van organische stof, bodemstructuur en bodemleven. Al deze kengetallen van bodemvruchtbaarheid worden momenteel niet op routinebasis geanalyseerd.

Résumé

Sur les sols fertiles, des systèmes de production agricoles à haut rendement, indispensables pour une agriculture rentable et nourrir la population mondiale en constante augmentation, peuvent être aménagés. Partout dans le monde des cas de faible fertilité et même de déclin de fertilité des sols sont signalés, ce qui entraîne la dégradation des sols et réduit le rendement des cultures. Les efforts visant à ameliorer la fertilité des sols et le rendement des cultures en appliquant des engrais et des fumures peuvent entraîner des effets secondaires indésirables sur l'environnement. Tels que pertes d'éléments nutritifs, contribuant entre autres à la pollution de l'eau, à la perte de biodiversité et éventuellement au changement climatique . Cette thèse traite la fertilité des sols aux Pays-Bas.

L'agriculture aux Pays-Bas est l'une des plus productives au monde. Les Pays-Bas se classe avec la France à la deuxième place sur la liste des exportateurs de produits agricoles (fleurs, produits laitiers, viande et produits dérivés, fruits, légumes, bière, produits dérivés de l'amidon et des semences). Sa production par hectare est parmi les plus élevés au monde, ce qui peut être attribué en partie à sa grande fertilité du sol, en partie héritée des apports alluviaux anciens par la mer et les rivières et en partie acquise par le fumier et l'épandage d'engrais par les hommes/l'agriculture. Cependant, depuis 1980, les applications de fumier et d'engrais sont soumises à des réglementations.

Cette thèse vise à accroître la compréhension des variations spatiales et des évolutions de la fertilité du sol des parcelles agricoles aux Pays-Bas au cours du dernier siècle. Plus précisément, elle aborde les questions de recherche suivantes: i) quels changements ont eu lieu au niveau de la matière organique du sol (MO) et du phosphore (P) du sol au cours la période 1970 à 2000, ii) un sol avec une teneur en P moyenne ou faible peut-il évoluer vers un niveau agricole optimal , compte tenu d'un petit écart-type, lorsque ce même sol à l'état vierge est cultivé avec un grand savoir-faire, iii) comment la qualité de l'herbage répond t'-elle aux changements de la fertilité du sol dans la production laitière, iv) quelles sont les perceptions et les préoccupations des agriculteurs concernant la fertilité du sol et v) comment améliorer l'emploi des recommandations de fertilisation, en utilisant les nouvelles connaissances? Une grande base de données d'un laboratoire d'analyse des sols, du fumier et de l'herbage (BLGG) a été analysé statistiquement et un questionnaire a été menée.

La MO est généralement considérée comme la plus importante caractéristique de la fertilité des sols, englobant les aspects biologiques, chimiques et physiques de la fertilité du sol. De nombreux rapports à travers le monde dénoncent la diminution de la teneur en MO et les agriculteurs Néerlandais craignent qu'une diminution de la MO compromette la capacité de production du sol. Cependant, j'ai constaté que la teneur moyenne

en MO est restée stable ou même a augmenté au cours des dernières décennies pour les sols minéraux (chapitre 2). Pour ces sols, la teneur moyenne en MO est de 8,1% pour les prairies (0 - 10 cm, 2009) et 4,3% pour les terres arables (0-25 cm; 2004), bien au-dessus du seuil considéré comme «critique» de 3,4% . Ces résultats sur l'évolution du taux de la MO contrastent avec ceux observés en Angleterre, Pays de Galles, Flandre (Belgique), Bretagne (France), Norvège, Bavière (Allemagne) et Finlande, où une baisse générale a été signalée. Cette différence peut s'expliquer par les apports organiques externes importants et relativement élevés aux sols agricoles des Pays-Bas. Malgré un statut MO relativement élevé et constant aux Pays-Bas, de nombreux agriculteurs ont placé MO en premier sur la liste des inquiétudes futures concernant la fertilité des sols , indépendamment de la région ou du type de sol (chapitre 7). Les agriculteurs ont indiqué qu'ils aimeraient avoir plus d'informations sur la qualité de MO.

Au 20e siècle, les excédents moyens cumulés de P étaient de ~ 4500 kg P2O5 ha-1. Avec ces apports, l'état moyen P du sol sur les terres arables (Pw test) est passé de la classification agronomique »(amplement) suffisant» à «(relativement) élevé» au cours de la période 1971-2004. Remarquablement, le statut P sur prairie (P-Al test) est resté dans la fourchette optimale sur près de 4 décennies (chapitre 3, 5). Il est probable que certain P s'est accumulé dans le sous-sol. Les résultats d'un questionnaire (chapitre 4, 7) suggèrent que le facteur décisif pour le maintien d'un statut phosphaté au-dessus du niveau agronomique optimal est d'éviter les risques, puisque 45% des agriculteurs semblent vouloir atteindre ce niveau optimal, et > 70% des agriculteurs ont indiqué qu'ils ignorent si l'augmentation obtenue dans le statut P est réellement disponible pour les plantes. Toujours est-il que les agriculteurs approuvent également l'amélioration de P par l'attribution d'engrais et de fumier. Des solutions possibles pour prévenir l'évitement des risques incluent des recommandations de fertilisation P plus digne de confiance.

Toutefois, faire évoluer les idées sur les analyses de sol et les recommandations de fertilisation dans la pratique agricole n'est pas une chose facile parce que remplacer les tests / recommandations de fertilisation existants impliquent un effort très important d'évaluation des nouveaux tests. A cet effet, un programme en trois étapes pour l'introduction de nouveaux tests de sol a été développé (chapitre 6): (i) mise au point de nouvelles analyses de sol prometteuses, (ii) créer des modèles de régression entre les anciennes et les nouvelles analyses de sol, et (iii) mettre en œuvre le nouveau test pas à pas par des essais de fertilisation des sols. De cette façon, les connaissances fondées sur les anciennes analyses de sol peuvent être utilisées jusqu'à ce que les nouveaux tests et les réponses ultérieures des cultures ont été suffisamment validées. Cette introduction progressive a été utilisée avec succès pour les recommandations P et peut être appliquée à d'autres nutriment.

Enfin, les agriculteurs sont conscients de l'importance de la fertilité du sol et aimeraient d'avantage d'informations sur la structure et la vie du sol (ces paramètres ne sont pour l'instant pas encore déterminés de façon routinière). Le nombre croissant des caractéristiques chimiques du sol analysées et de l'intérêt porté sur les caractéristiques physiques et biologiques offrent aux agriculteurs des Pays-Bas une chance pour mieux contrôler et améliorer encore la fertilité des sols, afin d' optimiser le rendement et la qualité des cultures.

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ANNEX

ANNEX I:
WRITTEN QUESTIONNAIRE ON SOIL TESTS

ANNEX II:
STATISTIC RESULTS OF THE QUESTIONNAIRE

ANNEX I: Written questionnaire on soil tests

1. What kind of agricultural holding do you have?
   a. Arable farm
   b. Dairy farm
   c. Horticultural farm
   d. Other, ...

2. What is the acreage of your farm?
   a. <20 ha
   b. 20-40 ha
   c. 40-60 ha
   d. 60-80 ha
   e. >80 ha

3. My company is located in the (Dutch) province
   - ☐ Groningen
   - ☐ Flevoland (excluding North East Polder)
   - ☐ North Brabant
   - ☐ Zealand
   - ☐ North East Polder
   - ☐ Other, ...

4. What is your crop rotation?

   ....

5. Did you have your soil sampled in the last 10 years?
   (multiple answers possible)

- ☐ Yes, standard soil tests (P and K and pH etc.) ***(proceed to question 7)***
- ☐ Yes, mineral N_analysis ***(proceed to question 7)***
- ☐ No ***(proceed to question 6)***

6. Why did you not have your fields sampled in het last 10 years?

   (multiple answers possible)

   - ☐ The results (soil status) are always the same
   - ☐ Too expensive
   - ☐ The report is not clear
   - ☐ The fertilization recommendations are not clear
   - ☐ The recommendations are not realistic
   - ☐ The fertilization recommendations are outdated
   - ☐ The fertilization recommendations are based on too low crop yields
   - ☐ Other, ...

→ Proceed to question 10

7. What are the most important outcomes of the soil test/fertilization research (using 1 to indicate the most important, 2 to indicate the second most important and 3 the third most important).

   a. Phosphorus (P) status
   b. Potassium (K) status
   c. Magnesium (Mg) status
   d. Soil organic matter content
   e. Soil texture (clay) percentage
   f. Calcium carbonate ($CaCO_3$) content
   g. The fertilization recommendations
   h. Other, ...

8. For which crops do you find information about soil status (N status, P status, K status, etc.) most important, or is it equally important for all crops?

9. What is lacking on the current (soil) report?

   (multiple answers possible)

   - ☐ Nothing
   - ☐ Clarity; the report is too complicated
   - ☐ (more) information about soil structure
   - ☐ (more) information about soil calcium status
   - ☐ (more) information about the quality of soil organic matter
   - ☐ (more) information about soil biological characteristics
   - ☐ (more) focus on micronutrients
   - ☐ (more) focus on local yield potential
   - ☐ Integration with plant parasitic nematodes
   - ☐ Other, ...

10. Who or what is important when setting up a fertilization plan (use 1 to indicate the most important, 2 to indicate the second most important, and 3 the third most important, etc.)

    a. My agricultural advisor/agricultural extension services

    b. The results of the soil test

    c. Information in agricultural magazines

    d. My own knowledge and experience

    e. Information of farmers' study group

    f. Other, ...

11. What kind of fertilizer(s) do you apply?

    (several answers possible)

- ☐ Nitrogen (N) fertilizer
- ☐ Phosphorus (P) fertilizer
- ☐ Potassium (K) fertilizer
- ☐ Calcium (among other gypsum, burn lime, etc.)
- ☐ Pig slurry
- ☐ Chicken manure
- ☐ Dairy cattle slurry
- ☐ Compost
- ☐ Other, ...

12. What are the reasons for using animal manure or compost? (use 1 to indicate the most important, 2 to indicate the second most important, etc.).

    a. To supply nutrients for my crops (N, P, K, etc.)

    b. To maintain soil organic matter level

    c. It is/was an extra source of income

    d. For soil disease suppressiveness

    e. Other, ...

13. Do you take measures to improve soil fertility?

    (multiple answers possible)

    - ☐ No, soil fertility is all right
    - ☐ No, however, in recent history a lot of measurements have been taken to improve soil fertility
    - ☐ Yes, I apply animal manure and/or compost
    - ☐ Yes, I exchange with grassland fields
    - ☐ Yes, I take notice of soil fertility through choices in my crop rotation
    - ☐ Yes, other, ...

14. Did you alter your fertilization strategy in the last 10 years?

    (multiple answers possible)

    - ☐ Yes, because of legislation
    - ☐ Yes, I pay more attention to micronutrients
    - ☐ Yes, I pay more attention to soil organic matter supply
    - ☐ Yes, I pay more attention to lime status (pH)
    - ☐ Yes, I pay more attention to soil structure
    - ☐ Yes, because of the prices of artificial fertilizers
    - ☐ Yes, I consider the prices of animal manure
    - ☐ Yes, more compost
    - ☐ No
    - ☐ Other,................

15. Which soil P status do you aim for?

    Give the answer you most identify with (only 1 answer).

    - ☐ I do pay attention to the soil P status; however, I do not have a multiannual plan regarding soil P status of my fields
    - ☐ The optimal range as indicated on the soil report
    - ☐ A soil P status above the optimal range as indicated on the soil report
    - ☐ A soil P status below the optimal range as indicated on the soil report
    - ☐ I do not really pay attention the soil P status of my fields
    - ☐ My predecessor already effected a sufficient soil P status
    - ☐ Other, ...

16. Soil laboratory BLGG together with, among others, Soil Quality of Wageningen University try to improve the fertilization recommendations for P. An improved fertilization recommendation should ensure an improved allocation of P over several parcels. Do you find this a positive development? (only 1 answer)

☐ No, with new legislation (restricted P application) there will be no room for P fertilization anyway

☐ Yes, because it will be increasingly important to use the P fertilizer (stocks) as optimal as possible on my several fields

☐ No, current recommendation is sufficient

☐ Yes, when there are good results from scientific research, it should be 'translated' to the field

☐ Other, ...

17. The P-Al method is a method to indicate the soil P **quantity** status. In which of the mentioned statements do you recognise yourself most.

    (multiple answers possible)

    ☐ It is important to know if the soil quantity status is well enough to continuously supply my crops with sufficient P throughout the growing season

    ☐ It doesn't matter what is measured, as long as the recommendations are good

    ☐ The added value of P-Al (quantity measurement) should be better communicated to farmers

    ☐ Whatever is measured, a small application of P at the start of the growing season is – in my opinion – necessary (for several crops)

    ☐ Other, ...

18. P-$CaCl_2$ is an indicator of **plant available phosphorus**. In which of the mentioned statements do you recognise yourself most?

    (multiple answers possible)

    ☐ The added value of plant available P should be better communicated to farmers

    ☐ Whatever is measured, a small application of P at the start of the growing season is – in my opinion – necessary (for several crops)

    ☐ I find it important to know whether there is enough plant available P in the soil

    ☐ It doesn't matter what is measured, as long as the recommendations are good

    ☐ Other, ...

19. A question regarding P fertilization in your company. In which of the mentioned statements do you recognise yourself most?

    (1 answer)

    ☐ When fertilizing, I pay attention to the **soil** P(w) status

    ☐ When fertilizing, I consider my **crop** (and I do not mind so much the soil P(w) status)

    ☐ I apply animal manure, with that, I automatically give P

    ☐ Other, ...

20. When looking back in history, we can see that – in a lot of areas – soil P(w) status has increased. Did you, or did your predecessors, consciously aimed at increasing soil P status of your soil (multiple answers possible).

    ☐ No

    ☐ Yes, with animal manure

    ☐ Yes, with compost

    ☐ Yes, with green manure

    ☐ Yes, through my crop rotation (grassland, grass seed, etc.)

    ☐ Yes, with artificial fertilizer

    ☐ Yes, by – among others – following soil P(w) status narrowly

    ☐ Other,....................

21. Another question regarding the increase in soil P status of agricultural land. In which statement do you recognise yourself best (multiple answers possible).

    ☐ I would have expected an increase in soil P(w) status of arable land in my region

    ☐ An increase in soil P(w) status is good, however, I am afraid the soil P status will decline again rapidly considering new (restrictive) regulations

    ☐ The increase in soil P(w) status gives me no assurance whatsoever that my crops will have sufficient P (from soil) at the start of the growing season

    ☐ An increase is good, however, which part is and will remain available for my crops?

- ☐ My predecessor did improve soil P(w) status; however, so further improvements are necessary
- ☐ Soil P(w) status did not increase at all
- ☐ Other, ...

22. In the last decades, soil K status did increase too. How do you explain this increase? (multiple answers possible)
    - ☐ I do not know
    - ☐ By use of manure
    - ☐ By use of compost
    - ☐ By land exchange (with grassland)
    - ☐ By use of artificial fertilizer
    - ☐ Other, ...

23. Concerning soil fertility, I worry most about (please rank, 1 = most important, 2 = second most important, etc.).
    a. Soil organic matter status
    b. P status
    c. Ca status
    d. Soil structure
    e. Soil biological status
    f. Plant parasitic nematodes
    g. I do not worry
    h. Other, ...

24. I would like to mention the following regarding P/soil tests/soil fertility

....

25. Finally, several general questions

    I am

    - ☐ man
    - ☐ female

26. My highest level of education is

    - ☐ Secondary school
    - ☐ (Lower) agricultural education (In Dutch: LAS)
    - ☐ Agricultural vocational education and training (In Dutch: MAS)
    - ☐ Other vocational educations and training (not agricultural) (In Dutch: MBO)
    - ☐ Agricultural college (In Dutch: HAS)
    - ☐ Other colleges (so no agricultural college) (In Dutch, HBO)
    - ☐ Wageningen University (Agricultural University)
    - ☐ Other universities (so no agricultural university)
    - ☐ Other, ...

27. The soil type on my farm is (multiple answers possible)

    - ☐ Dune sand and marine sand
    - ☐ (acidic) sandy soils
    - ☐ Marine clay
    - ☐ River clay
    - ☐ Reclaimed peat soils
    - ☐ Peaty clay soils and peaty soils
    - ☐ Other, ...

28. I am (age)

    - ☐ Younger than 25
    - ☐ Between 25 and 35

- ☐ Between 36 and 45
- ☐ Between 46 and 55
- ☐ Between 56 and 65
- ☐ Older than 65

29. Anonymous
    - ☐ Yes
    - ☐ No

ANNEX II: Statistic results (χ2) of the questionnaire

Questions	age < 45 versus > 45 year	education high (college or university) versus lower	Basic soil tests versus Both (basic + Nmin)	crop rotation intensive (<1 : 5) versus extensive	plant based versus soil based	Arable land sand versus horticultural land sand	Pure arable farming versus mixed farming	Arable farming sand versus arable farming clay
Type of farm								
1a Arable farm								
1b Dairy farm								
1c Horticultural farm	<45 *			Intensive **				
1d Other farm								
Mixed farm (including livestock)								
Acreage								
2a <20 ha								Sand ***
2b 20-40 ha								
2c 40-60 ha								
2d 60-80 ha								
2e >80 ha								
<60 ha								
>60 ha								
Region								
3a Grongingen						Arable **		Sand **
3b Flevoland (excluding North East Polder)			Both *					Clay ***
3c North Brabant				Intensive *		Horticulture *	Mixed **	Sand ***
3d Zealand				Extensive *				
3e North East Polder								
3f Other								
4 rotation 1 : 1							Mixed ***	Sand *
4 rotation 1 : 2								
4 rotation 1 : 3								
4 rotation 1 : 4								
4 rotation 1 : 5								
4 rotation 1 : 6 or more								
4 Crop rotation intensive (< 1 : 5)								
4 Crop rotation extensive (1: 5 and more)								
Soil test								
5 Standard soil test								
5 Soil test for mineral N								Clay *
5 No					Plant *			
5 Both standard and mineral N								Clay *
No soil tests								
6 The results (soil status) are always the same							Mixed *	
6 Too expensive								
6 The report is not clear								
6 The fertilization recommendations are not clear								
6 The recommendations are not realistic								
6 The fertilization recommendations are outdated								
6 The fertilization recommendations are based on too low crop yields								
6 Other								
Important on the report								
7a Phosphorus (P) status								
7b Potassium (K) status						Arable *		
7c Magnesium (Mg) status								Sand ***
7d Soil organic matter content								
7e Soil texture (clay) percentage								
7f Calcium carbonate ($CaCO_3$) content						Hortculture *		Sand *
7g The fertilization recommendations								
7h Other						Arable *		Sand ***
7a Score						Arable **		
7b Score				Extensive **				Sand *
7c Score								Sand ***
7d Score								Clay *
7e Score			Both **					
7f Score							Mixed **	
7 g Score	>45 *			Intensive ***			Mixed ***	
7 h Score	<45 ***	High **						Sand ***
Soil status important for:								
8a Equally important for all crops								
8b First mentioned crop								
8c Second mentioned crop								
8d Third mentioned crop								
8e Fourth mentioned crop								

Statistic results (χ2) of the questionnaire, continued (part 2)

Questions	age < 45 versus > 45 year	education high (college or university) versus lower	Basic soil tests versus Both (basic + Nmin)	crop rotation intensive (<1 : 5) versus extensive	plant based versus soil based	Arable land sand versus horticultural land sand	Pure arable farming versus mixed farming	Arable farming sand versus arable farming clay
Lacking on the report								
9a Nothing								
9b Clarity; the report is too complicated								
9c (more) information about soil structure								
9d (more) information about soil calcium status								
9e (more) information about the quality of soil organic matter								
9f (more) information about soil biological characteristics								
9g (more) focus on micro nutrients								
9h (more) focus on local yield potential								
9i Integration with plant parasitic nematodes		High *						
9j Other, ……………..								
Making a fertilization scheme								
10a My agricultural advisor/agricultural extension services								
10b The results of the soil test								
10c Information in agricultural magazines					Plant **			
10d My own knowledge and experience								
10e Information of farmers' study group								
10f Other								
10a Score		Lower *	Both ***				Pure arable *	Clay *
10b Score		Lower ***						
10c Score					Plant ***			
10d Score	<45 *	High **			Plant *			
10e Score		High *			Plant **			Clay *
10f Score			Basic *	Intensive **	Soil *			
Kind of fertilzer								
11a Nitrogen (N) fertilizer								
11b Phosphorus (P) fertilizer								Clay *
11c Potassium (K) fertilizer								
11d Calcium (among other gypsum, burn lime, etc.)								
11e Pig slurry								
11f Chicken manure			Both *					Clay *
11g Dairy cattle slurry							Mixed **	
11h Compost								
11i Other								
Reason for organic matter								
12a To supply nutrients for my crops (N, P, K, etc.)								
12b To maintain soil organic matter level								
12c It is/was an extra source of income								
12d For soil disease suppressiveness								
12e Other							Mixed *	
12a Score								
12b Score			Both ***		Plant *			
12c Score						Arable **		
12d Score			Both ***		Plant *			
12e Score		High ***						
Improving soil fertlity								
13a No, soil fertility is good								
13b No, however, in recent history a lot of measurements…								
13c Yes, I apply animal manure and/or compost								
13d Yes, I exchange with grassland parcels								
13e Yes, I take notice of soil fertility through choices in my crop rotation								
13f Yes, other								
Change in strategy								
14a Yes, because of legislation								
14b Yes, I pay more attention to micro nutrients								Sand **
14c Yes, I pay more attention to soil organic matter supply								
14d Yes, I pay more attention to lime status (pH)								
14e Yes, I pay more attention to soil structure								
14f Yes, because of the prices of artificial fertilizers								
14g Yes, I consider the prices of animal manure			Both *					
14h Yes, more compost								
14i No								
14j Other								

Statistic results (χ2) of the questionnaire, continued (part 3)

Questions	age < 45 versus > 45 year	education high (college or university) versus lower	Basic soil tests versus Both (basic + Nmin)	crop rotation intensive (<1 : 5) versus extensive	plant based versus soil based	Arable land sand versus horticultural land sand	Pure arable farming versus mixed farming	Arable farming sand versus arable farming clay
Soil P status								
15a I do pay attention to the soil P status; however, I do not have a multiannual…								
15b The optimal range as indicated on the soil report					Soil *			
15c A soil P status above the optimal range as indicated on the soil report	>45 *							
15d A soil P status below the optimal range as indicated on the soil report								
15e I do not really pay attention the soil P status of my fields								
15f My predecessor already effected a sufficient soil P status								
15g Other, …………….			Basic *					
New P recommendation								
16a No, with new legislation (restricted P application) …								Sand *
16b Yes, because it will be increasingly important to use the P fertilizer stocks…								
16c No, current recommendation is sufficient								
16d Yes, when there are good results from scientific research, …								
16e Other								
Soil P quantity								
17a It is important to know if the soil quantity status is well enough…								
17b It doesn't matter what is measured, as long as the recommendations are good					Plant **			
17c The added value of P-Al (quantity measurement) should be better communicated								
17d Whatever is measured, a small application of P at the start…								
17e Other								
Soil P intensity								
18a The added value of plant available P should be better communicated to farmers								
18b Whatever is measured, a small application of P at the start…								
18c I find it important to know whether there is enough plant available P in the soil								
18d It doesn't matter what is measured, as long as the recommendations are good					Plant **			
18e Other								Sand *
P fertilization statements								
19a When fertilizing, I pay attention to the **soil** P status					[redacted]			
19b When fertilizing, I consider my **crop** (and I do not mind so much the soil P status)			Basic *					
19c I apply animal manure, with that, I automatically give P					Plant *			Clay **
19d Other								
Increasing P status								
20a No	<45 *							Sand *
20b Yes, with animal manure								
20c Yes, with compost								
20d Yes, with green manure								
20e Yes, through my crop rotation (grassland, grass seed, etc.)								
20f Yes, with artificial fertilizer				Extensive *				Clay *
20g Yes, by – among others – following soil P status narrowly								
20h Other								
Soil P status (2)								
21a I would have expected an increase in soil P status of arable land in my region								
21b An increase in soil P status is good, however, I am afraid…legislation								
21c The increase in soil P status gives me no assurance whatsoever								
21d An increase is good, however, which part is and will remain available								
21e My predecessor did improve soil P status; however,...								
21f Soil P status did not increase at all								
21g Other								
Increase in soil K status								
22a I do not know								
22b With manure								
22c With compost								
22d By land exchange (with grassland)								
22e With artificial fertilizer	>45 *							
22f Other								

Statistic results (χ2) of the questionnaire, continued (part 4)

Questions	age < 45 versus > 45 year	education high (college or university) versus lower	Basic soil tests versus Both (basic + Nmin)	crop rotation intensive (<1 : 5) versus extensive	plant based versus soil based	Arable land sand versus horticultural land sand	Pure arable farming versus mixed farming	Arable farming sand versus arable farming clay
Worry about								
23a Soil organic matter status								
23b P status								
23c Ca status			Both *					
23d Soil structure								
23e Soil biological status								
23f Plant parasitic nematodes								
23g I do not worry								
23h Other				Extensive *				
23a Score		Lower ***				Horticultrue *		
23b Score		Lower *				Arable ***		
23c Score			Both **	Intensive **				
23d Score								
23e Score	<45 *				Plant **	Horticulture *		
23f Score	<45 *	High *		Intensive ***		Arable *	Pure arable **	
23g Score	<45 ***						Mixed ***	
23h Score		High *		Extensive ***	Plant ***			
Gender								
25a man								
25b female								
Education								
26a Secondary school								
26b (Lower) agricultural education (In Dutch: LAS)	>45 *			Intensive *				Sand ***
26c Agricultural vocational education and training (In Dutch: MAS)								
26d Other vocational educations and training (not agricultural) (In Dutch: MBO)								
26e Agricultural college (In Dutch: HAS)								
26f Other colleges (so no agricultural college) (In Dutch, HBO)								
26g Wageningen University (Agricultural University)								
26h Other universities (so no agricultural university)								
26i Other							Mixed *	Sand *
no (agricultural) college or university								
(agricultural) college or university								
Soil type								
27a Dune sand and marine sand								
27b (acidic) sandy soils			Basic **	Intensive *			Mixed *	
27c Marine clay								
27d River clay								
27e Reclaimed peat soils				Extensive *				
27f Peaty clay soils and peaty soils								
27g Other, ……………								
Age								
Younger than 25								
Between 25 and 35								
Between 36 and 45		High *						
Between 46 and 55								
Between 56 and 65								Sand *
Older than 65								
< 46 years								
>45 years								
Anoymous								
Yes								Sand *
No								
Extra								
Arable farming sandy soil			Basic **					
Horticulture sandy soil				Intensive **				
Arable farming sandy soil			Basic **					
Arable farming marine clay soil								
Arable farming								
Mixed farming (arable - livestock)								

* = p<0.05; ** = p<0.01; *** = p< 0.001

Indicated is, if a characteristic is – in comparison to the another characteristic – more present than expected. So, for example (question 27b):

- There are more 'basic' soil samples on (acidic) sandy soils in compared to the 'both' (combination basic soil sample and Nmin), in other words, on (acidic) sandy soils, relatively few Nmin is sampled.
- There are more 'intensive' crop rotations on acidic sandy soils then one would expect, so there are relatively less 'extensive' crop rotations on (acidic) sandy soils.
- The combination arable farms including livestock farming (mixed) is more frequent on (acidic) sandy soils, compared to pure arable farms.

Cells in grey are obviously very high related and are not mentioned, the cells in black are the investigated characteristics.

Acknowledgements

When I started my study Soil Processes in 1992, soil fertility was definitely not a very hot topic; the subject of my second research project at Wageningen University (soil life and soil structure) was not something I brought up in conversations. Even when I started this research in 2007 farmers were generally less interested in soil fertility and plant nutrition than they were in cattle feeding or crop protection. That has changed considerably in the last years and I am therefore glad to present this thesis as part of the increasing interest in this field.

First of all I would like to thank BLGG group's general manager H. Hekman. Henri, when I suggested doing a PhD research in addition to my regular work, you directly responded supportively. Thank you for this great opportunity.

Of course I would like to thank Prof. O. Oenema, my promotor. Oene, the idea to work together was on my mind for quite a while already, I am therefore glad I had the opportunity to put my ideas into practice. Thank you for your enthusiasm, and support during this entire project. I thank Dr. A. Termorshuizen, my co-promotor. Aad, especially in the end we worked intensively together on this 'project'. Thank you for all your time and support. Oene, Aad, I hope we can continue working together. There are still a lot of things to put on paper.

A warm thank you for everyone involved in the chapters of this thesis and the accompanying poster and oral presentations. I learned a lot from it and it was a pleasure working with you from the very first ideas until the finishing touches of the final dissertation. Thank you Joke van Wensem, Phillip Ehlert, Herman Vedder, Frans van Bohemen, Peter Kuikman, and Oscar Schoumans and more recently Debby van Rotterdam – Los, Martijn van Oostrum, Wim Bussink and Gerard Abbink.

I am not really sure whether I should thank my – daily job – BLGG AgroXpertus colleagues... Most pronounced was the remark that I would never ever, ever make it... (justified by the argument that I would be too busy anyway). Still, working in a very lively, dynamic team made life easier, thank you all for that: Alie Hissink, Pieter Brons, Jos Erkens, Frans Giesen, Karen Oerlemans, Han van Goor, Ton van Gastel, Martijn van Rossum, Inez Sinia (thank you for helping me with the layout!), Natasja Poot, Jan Hardeman, Piet Linders, Marcus Wiebinga, Frank Geerdink, Martijn van Oostrum, Nathalie Zwaardemaker, and Klaas Bouwknegt. A special 'thank you' to Jan Bakker, Jan I really enjoyed our trips (a.o. Bonn and Vianden). You were always interested in the development of my thesis. Thank you Erikjan van Huet Lindeman, and Martin Vervoorn for your support (we sure implemented a lot of soil knowledge in the last 10 years).

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Nicest were perhaps the congresses in Luxemburg and Berlin. I met many people there; a dairy farmer from New Zealand with whom I discussed about calcium fertilization, friendly, interesting scientists from Asia, the Middle East and from relatively nearby some great people from the Czech Republic. Among more we discussed a lot of different soil fertility issues everywhere. Thank you all.

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Arjan Reijneveld, Oktober 2013

voor moeder

CURRICULUM VITAE (DUTCH)

Arjan (Jan Adriaan) Reijneveld werd geboren op 5 juni 1970 te Leiden. Na de middelbare school koos hij voor de studies Rundveehouderij en Agrarische bedrijfskunde aan de Christelijke Agrarische Hogeschool te Dronten. Na diverse praktijkstages, o.a. een melkveehouderijstage in Luxemburg, deed hij zijn halfjaarstage bij de afdeling Commerciele Zaken van Interpolis alwaar hij onderzoek deed naar het concept 'totaaladvisering bij de agrariër'. In 1992 haalde hij zijn diploma's in Dronten. Vervolgens volgde hij de studie Bodem, Water & Atmosfeer aan Wageningen Universiteit in de richting Procesbodemkunde met specialisaties Plantenvoeding & bemesting en Bodembiologie. Zijn doctoraalonderzoeken betroffen 1) Onderzoek naar de schade die gewassen ondervinden op zure (aluminium) gronden en de rol die magnesiumbemesting speelt in het verminderen van die schade en 2) Onderzoek naar de invloed van bodemleven op de stabiliteit van bodemaggregaten en de mineralisatie van organische stof. Na de afronding van zijn studie (1995) werkte hij op de vakgroep Bodemkunde en Geologie (WUR) aan het project 'Grain-size determination by laser diffraction'. Daarna werd hij door het Nutriënten Management Instituut (NMI) o.a. gedetacheerd bij Blgg Oosterbeek om onderzoek te doen naar het N-model in het project Kompas. Van september 1997 tot en met mei 1999 werkte hij bij Blgg Oosterbeek. Tijdens deze periode hield hij zich bezig met het aanpassen van het bemestingsadviesmodel (BAP) aan de nieuwste inzichten en hield hij bijeenkomsten met eindgebruikers (veehouders). Daarna werkte hij als onderzoeker op Plant Research International (WUR) bij de business unit Agrosysteemkunde. Het accent van zijn onderzoek lag daar op nutriëntenstromen. Hij was lid van het projectteam proefbedrijf "De Marke", verantwoordelijk voor de samenwerking met Institut Technique de Cereals et Fourrages (praktijkonderzoek in Frankrijk) en verantwoordelijk voor de invulling van het thema bodemvruchtbaarheid binnen het project Koeien & Kansen. Daarna werd hij senior productmanager bemesting bij BLGG AgroXpertus. Daar introduceerde hij o.a. het product "Bemestingswijzer" en de laatste jaren ligt de focus op het implementeren van het intensiteit, buffering capaciteit en kwantiteit concept in de markt. Hij is daarnaast ook lid van de diverse bemestingsadviescommissies. Van 2000 tot en met 2008 was hij secretaris van de Nederlandse Vereniging voor Weide- en Voederbouw. Tevens was hij penningmeester van het Diaconaat van de PKN te Wageningen en onderdeel van het team van 'De Wijnerij' (wijnverkoop in de uiterwaarden te Wageningen). Voornamelijk naast zijn reguliere werkzaamheden startte hij in 2007 met onderzoek met als resultaat het onderliggende proefschrift. Arjan is getrouwd met Rolien en samen hebben ze drie kinderen; Roel (2004), Carlein (2006) en Aron (2007).

CURRICULUM VITAE

Arjan (Jan Adriaan) Reijneveld was born June, 5, 1970 in Leiden, the Netherlands. After his higher general secondary education, he studied animal husbandry and agricultural business administration at the Christian Agricultural College (CAH) at Dronten. After several practical periods at farms (e.g. dairy farms in Luxemburg and Nieuwveen, and an arable farm at Nieuw Vennep), he spent half a year at agricultural insurance company Interpolis, where he carried out a market research on the effect of the concept of so-called 'total advice' on customer relations. In 1992 he finished at CAH with a BSc-certificate. Then, he started at Wageningen University to study Soil, Water & Air, specialization plant nutrition & fertilization and soil biology. He performed two research projects: 1) Analysis of Al-toxicity on maize, sunflower, and soy beans and alleviating the negative effects of acid soils by Mg application, and 2) Soil structure and decomposition, amounts and decomposability of organic matter in macro-aggregates. After he obtained his MSc in 1995, he worked for a short time at the Department of Soil Science and Geology of Wageningen University on the project 'Grain size determination by laser diffraction'. He subsequently worked at the Nutrient Management Institute (NMI) at Wageningen, where he was, a.o., detached at the Laboratory for Crop and Soil Analysis (now BLGG AgroXpertus) at Oosterbeek to validate a nitrogen-flow model (model Whitmore). From September 1997 till May 1999 he worked at BLGG AgroXpertus to, a.o., update the Fertilizer Advisory Program according to the latest insights. Subsequently, he worked as scientist nutrient flows at Plant Research International (PRI) at Wageningen in the Business Unit Agrosystems group. He was member of the project team of the experimental farm 'De Marke', responsible for the collaboration between Institut Technique de Cereals et Fourrages (ITCF, France) and the PRI Agrosystems group, and he was also responsible for soil fertility within the Dutch nitrate project 'Cows and Opportunities'. He thereupon became senior product manager fertilization (soil quality) at BLGG AgroXpertus. An intermediary position which involves contacts with farmers, advisors, researchers, and policy makers. Implementing fertilization recommendations based on the intensity, buffering capacity, quantity concept into agricultural practice has been a major topic in the last years. He is member of several Dutch committees for fertilization recommendations. From 2000-2008 he was secretary of the Dutch Society for grassland and fodder crops (in Dutch: NVWV, European Grassland Federation member). He was treasurer of the diaconate (protestant church) of Wageningen and he was a member of the team 'De Wijnerij' (wine sales in the flood plaines of Wageningen). Mainly besides his regular duties he started in 2007 with the research which resulted in this thesis. Arjan is married to Rolien and the have three children: Roel (2004), Carlein (2006), and Aron (2007).

Publications

Scientific papers & Proceedings (not in this thesis)

Marinissen, J.C.Y., Reijneveld, J.A. & Van Breemen, N. 1995. Soil structure and decomposition - amounts and decomposability of organic matter contained in aggregates-. European Grassland Federation (www.europeangrassland.org), 1995. London, United Kingdom.

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See for other proceedings "education certificate".

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PE&RC PhD Training Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)

Literature study; introduction thesis; discussion forum at Plant Research International

Writing of project proposal (2.6 ECTS)

- Unravelling chances in soil fertility of agricultural land in the Netherlands

Post-graduate courses (3.9 ECTS)

- Introduction in R for statistical analysis (2008)
- Multivariate analysis (2009)
- Linear mixed models (2009)
- Generalized linear models (2009)
- Bayesian statistics (2009)

Laboratory training and working visits (4.5 ECTS)

- Biogass and grassland field experiments; Haus Riswick, Kleve, Germanay (2005)
- Comparison between fertilization recommendations in Belgium and in the Netherlands; Provinciaal Onderzoels- en Voorlichtingscentrum voor Land- en Tuinbouw, Rumbeke – Beitem, Belgium (2006)
- Laboratory methods discussions; BLGG, Oosterbeek, the Netherlands (2007 and 2010)
- Soil phosphorous tests in Germany and in the Netherlands; LUFA, Rostock, Germany (2008)

- Phosphate fertilization trials; Arbeidsgemeinschft Huttenkalk e.V., Germany (2008)
- Changes in soil organic matter; University Kiel, Germany (2009)
- Fertilization and climate change; Kali + S, Germany (2010)
- Soil phosphorous tests in Denmark and in the Netherlands; Knowledge Centre for Agriculture, Denmark (2011)

Deficiency, refresh, brush-up courses (4.2 ECTS)

- Access 2003 basic (2006)
- Access 2003 advanced (2007)
- Course dairy cattle feeding (2007)
- Basic statistics (2008)

Competence strengthening / skills courses (4.5 ECTS)

- Advanced language course; German (2002)
- Information literacy for PhD, including introduction in EndNote (2008)
- Scientific writing (2008)
- Soil nematodes courses (2012)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- Annual meeting (2009)
- The biobased economy (2010)
- Selling science (2010)
- Global soil fertility (2011)
- Innovation for sustainability (2011)

Discussion groups / local seminars / other scientific meetings (7.5 ECTS)

- Changes in soil organic matter; Petit Committee technical Committee Soil protection, TCB (2005)
- Meetings of the Dutch Association of Grassland and Fodder crops, Nederlandse Vereniging voor Weide- en Voederbouw (between 2005 and 2008)
- Dutch Soil Congress, Bodem Breed (2006)
- Café Seminar Sustainable Soil Management; Alterra, WUR (2007)
- Criteria for risk areas regarding soil organic matter, Alterra, Wur (2007)
- Dairy farming day; Animal Sciences group, WUR (2007)
- Precision farming; PPO and AGV, WUR (2007)
- Member of the Committee for fertilization; grassland and fodder crops; arable and vegetable crops; bulb flowers (between 2007 and 2013)
- 50 Years of field experiment; Ossenkampen, WUR (2008)
- Science day, and Organic matter day at BLGG Agroxpertus (2008)
- Developments in soil organic matter; WUR (2008)
- State of art and the future of fertilization; Antwerp, Belgium (2008)
- Meetings of/with Dutch Ministry of Agriculture (2009-2013)
- Workshop Climate Change; WUR (2009)
- Changes in soil organic matter; University Kiel, Germany (2009)
- Phosphate availability meetings; WUR (2010-2012)
- Soil tests and fertilization recommendations, discussion with Danish scientists (2011)
- Soil tests and fertilization recommendations, discussion with Polish scientists and farmers (2011)
- Soil tests and fertilization recommendations, discussion with Chinese delegations (2011 and 2012)

International symposia, workshops and conferences (9 ECTS)

- Journée Technique; oral presentation; ITCF, Nantes, France (2000)
- VDLUFA Congresses, Germany (2001 and 2012)
- Soil life and soil fertility congress; Bonn, Germany (2005)

- International symposium on organic matter dynamics in agro-ecosystems; poster presentation; INRA and University Poitiers, France (2007)
- 1st International Pasture Conference; oral presentation; Luxembourg (2008)
- Arbeidsgemeinschaft Grünland und Futterbau; poster presentation; Kleve, germany (2009)
- Soil fertility and soil productivity conference; oral presentation; Berlin, Germany (2010)
- European Grassland Federation, EGF; poster and oral presentation; Berlin, Germany (2010)
- Nutrihort; oral presentation; Ghent, Belgium (2013)

Credits

The photograph on the cover is taken in the spring of 2012 in Nieuwveen in the west of the Netherlands (Green Heart, see Chapter 5). It shows (mowed) rye grass on an old marine clay soil (19 % soil organic matter and 23% clay in the soil layer 0-10 cm).

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