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ORIGINAL ARTICLE

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 ~1950–2004, 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

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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 and Dechering 1938;

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 and Veenstra 1951; Van der Paauw and 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 and 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. 2010). 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 and 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 1971–2004. 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 (Fig. 1).

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. 2010).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 to 20 cm, 36 % from 0 to 22 cm, and 11 % from 0 to 25 cm. In 1999–2000, >98 % of the samples was taken from 0 to 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 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

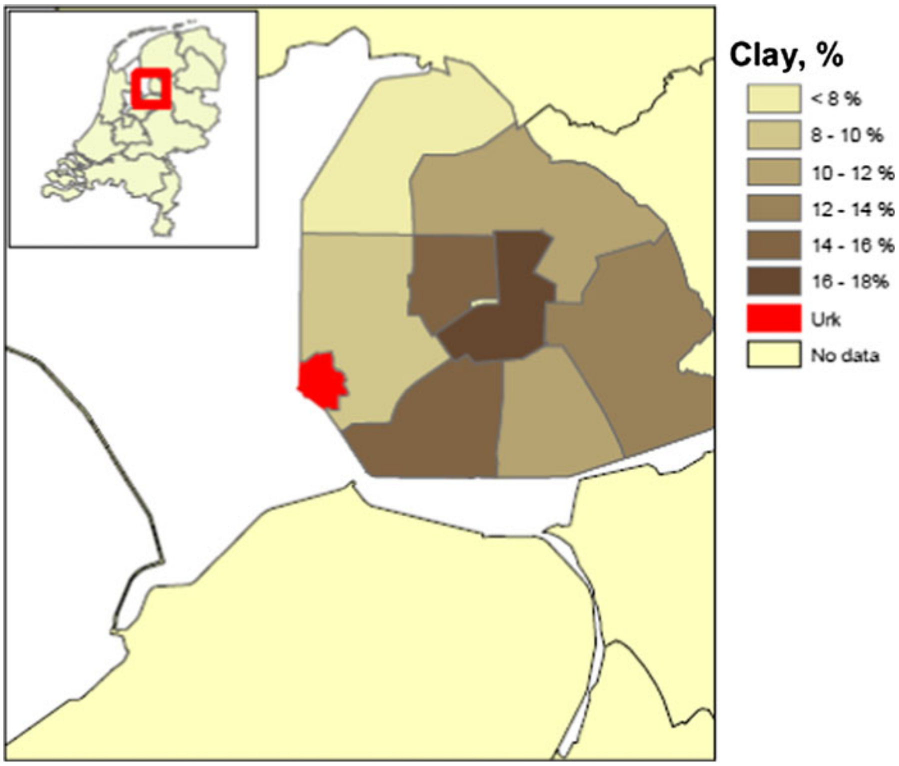

Fig. 1 The location of the Northeast Polder in the Netherlands and the average clay content (%) per postal code zone in this reclaimed land. The old isle *Urk* is also indicated (*red*). (Color figure online)

advised to give 50–75 % of the recommendation for broadcast applications.

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 (http//: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 and 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.

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 P_2O_5 ha^{-1}) on arable land for increasing soil Pw to the target range of 25–45 mg P_2O_5 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

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 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 to 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

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

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 and 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.

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 ($p < 0.001$; Fig. 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 (Fig. 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 (Fig. 3b) and the P–Al increased on average by 0.34 P–Al units $year^{-1}$. However, the number of soil samples was considerably

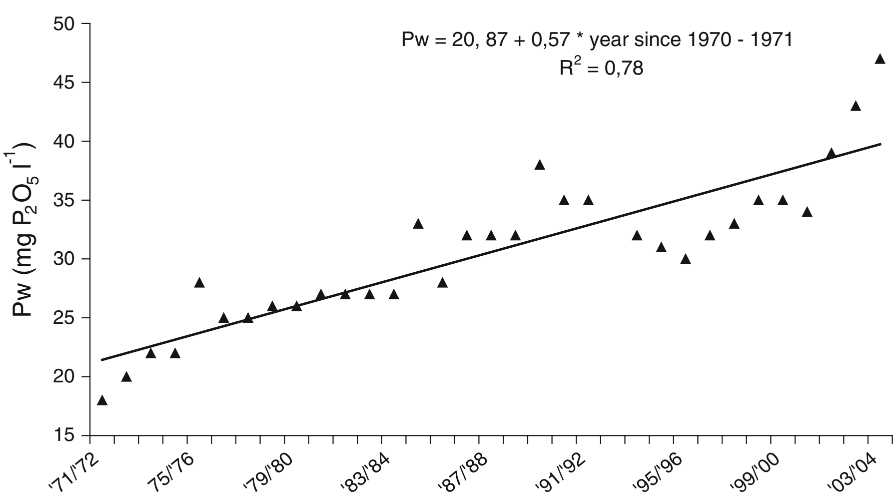

Fig. 2 Change in median Pw (mg P_2O_5 L^{-1}) on arable land in the Northeast Polder in the Netherlands from 1971 to 2004

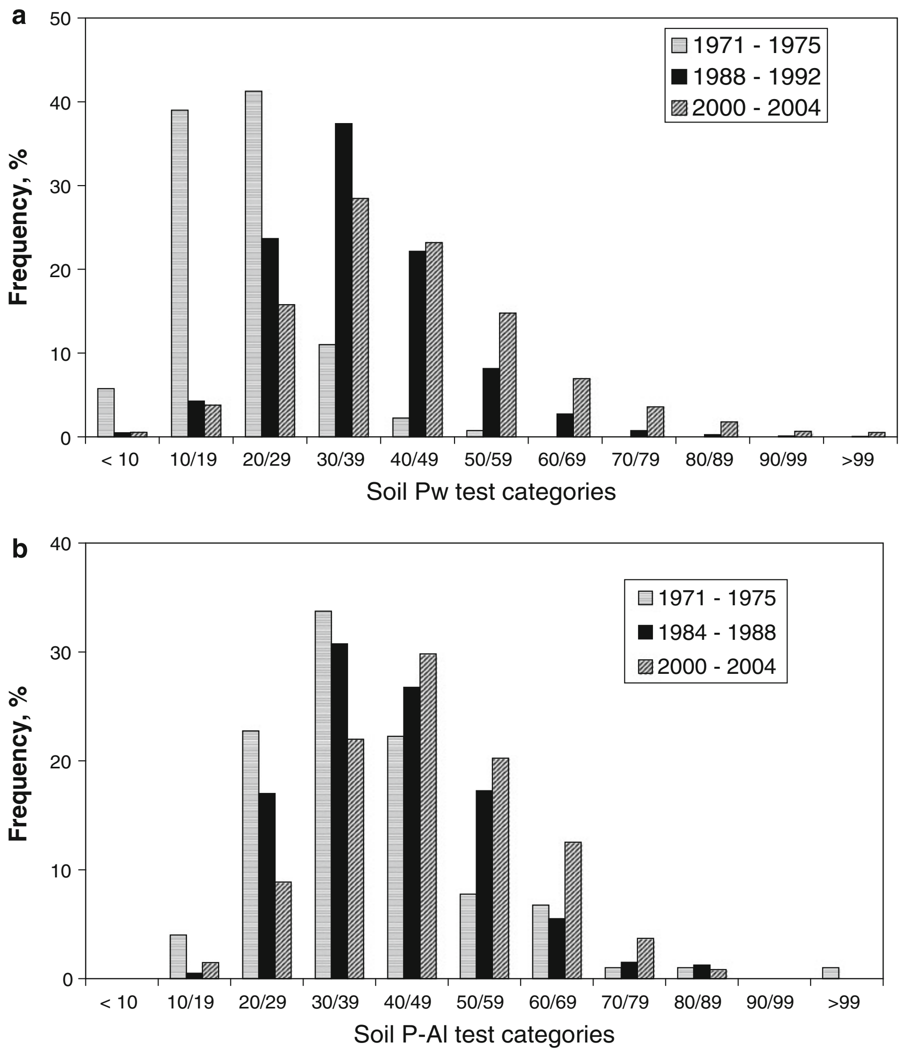

Fig. 3 Shift in frequency distribution of **a** soil Pw status on arable land and **b** P–Al status on grassland in the Northeast Polder

lower for grassland than for arable land (350 records were available for grassland and 6630 for arable land during the period 1996–2000).

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 (Table 5, Fig. 4).

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

Table 5 Variation in Pw status (mg P_2O_5 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

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 Northeast 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 Fig. 5.

The respondents were mostly between 46 and 56 years of age, 20 % had a BSc in agriculture, and >70 % had a technical education in agriculture (Fig. 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 1970 s till now, >70 % state that a high soil Pw test value does not give security about available soil P for crops.

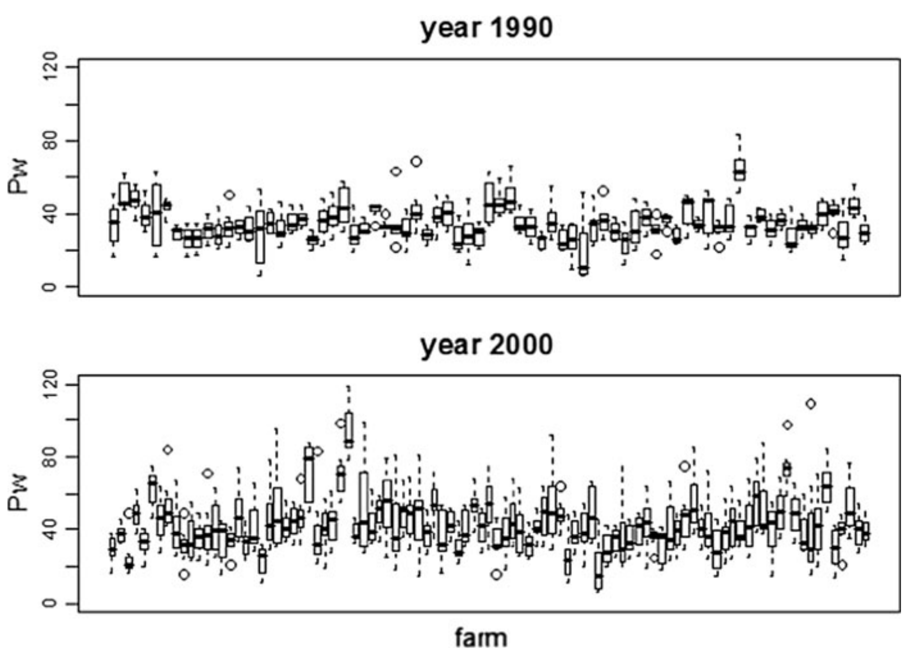

Fig. 4 Box plot of variation in Pw status (mg P_2O_5 L^{-1}) within farms for two periods

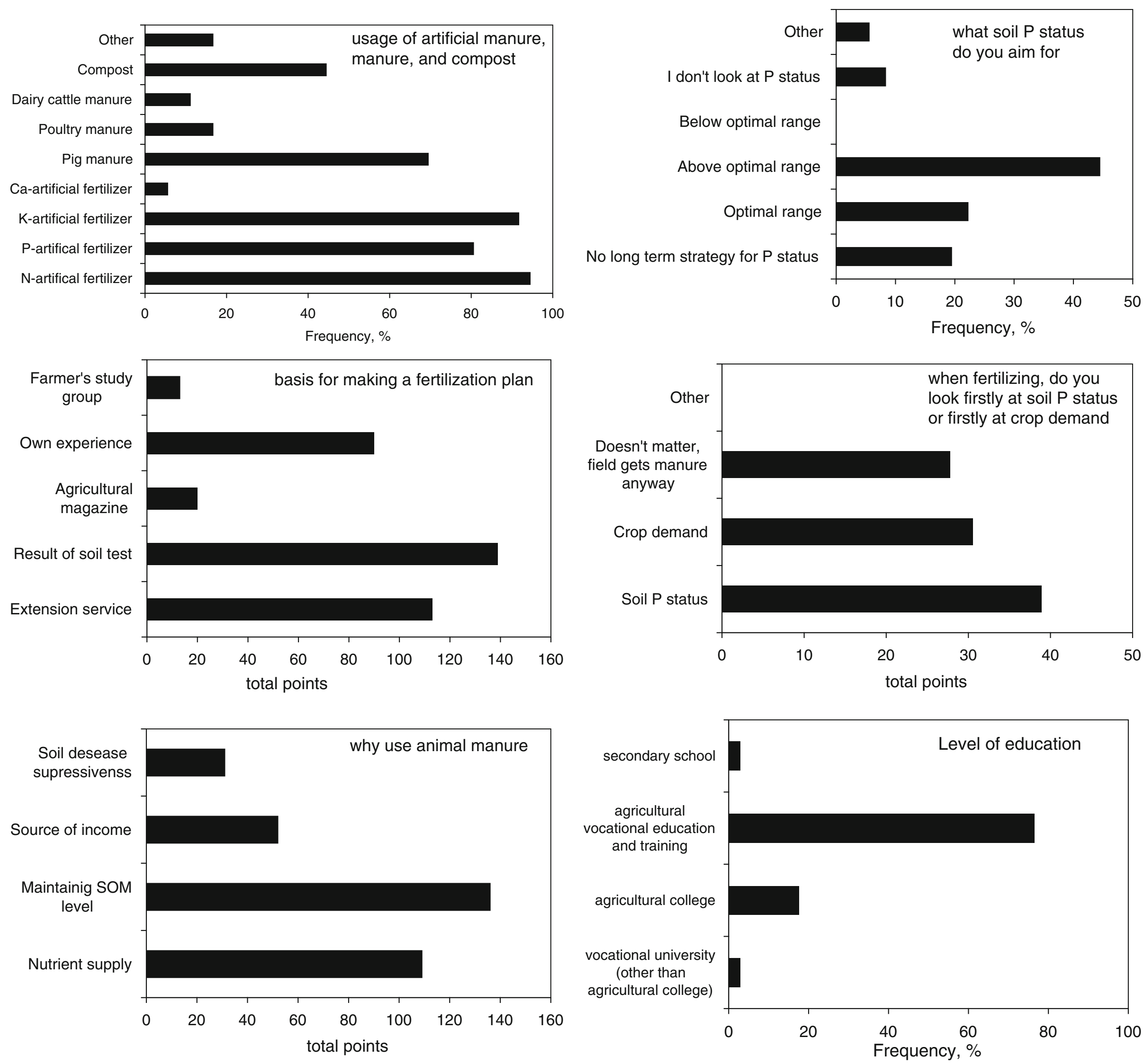

Fig. 5 Results of written survey; usage of manure (**a**), fertilization plan (**b**), reasons for usage of animal manure (**c**), soil P status (**d**), soil P status versus crop demand (**e**), level of education (**f**)

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 (Fig. 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. 2010). 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 (Fig. 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 (Fig. 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 and Torrent 2000; Robbins et al. 1999; Siddique and Robinson 2003; Van Wandruszka 2006; Cao and 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 (Fig. 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 and 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, 2010). Reijneveld et al. (2010) 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.

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