ACCOUNTING NUTRIENTS IN ANIMAL MANURES

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1 INTRODUCTION

The Danish Parliament passed *Action plans for the aquatic environment* in 1987, 1998 and 2004, a *Plan for Sustainable Agriculture* in 1991, and an *Action Plan to reduce Ammonia Emission* in 2001 (see Mikkelsen et al., 2005; Kronvang et al., 2008). As a result of the plans, The Danish Plant Directorate was authorized by the Minister of Food, Agriculture and Fisheries to lay down statutory orders on the agricultural use of nitrogen (N) with the aim of reducing nitrate leaching from fields. The annual statutory order is divided into two parts for nitrogen: one setting out standard N rates for each crop, and the other a substitution rate for N in animal manures that has to be taken into account in observing the standard N rate.

The standard N rates, which took effect starting with the 1993/94 growing season, depend on soil type, irrigation, and preceding crop, and are defined as the N rate required to obtain economically optimal yields. To meet the Nitrate Directive (EEC, 1991) the second *Action Plan for the Aquatic Environment* from 1998 stipulates a suboptimal N rate for crops corresponding to *c.* 90% of the N rate for economically optimal yields. The substitution rate for N in animal manures took effect starting with the 1993/94 growing season, and it has been tightened gradually ever since (Petersen & Sørensen, 2008, 2009). These regulations have, together with statutory orders determined by the Danish Environmental Protection Agency (DEPA) regarding application time and method, caused significant changes in the use of N in animal manure and mineral fertilizers. The most important change is the ban on slurry application in the autumn (from harvest to 1st February), taking effect from July 1993.

The average consumption of mineral fertilizer N has decreased concurrent with the introduction of regulations on the use of animal manure and an increased focus on the agricultural nitrogen cycle (Grant et al., 2007; Figure 1). The statutory orders derived by the actions plans concerns N, but the general awareness of utilization of nutrients in animal manure has, together with a high phosphorus (P) status in Danish soils, reduced the use of mineral fertilizer-P since 1980 (Maguire et al., 2009). The focus on nutrient utilization has also decreased the average application rate of potassium, particularly since 1990 (Figure 1).

In Denmark winter wheat covers one quarter of the cultivated land, but during the recent two decades the yields have stagnated (Petersen & Kristensen, 2010). While investigating the causes for this stagnation we examined the changes in the rate of mineral fertilizers applied to winter wheat for two typical farming systems: one using mineral fertilizer exclusively and another using mineral fertilizer as supplement to nutrients applied in animal manures (Petersen & Knudsen, 2010). The aim of this presentation is to demonstrate the change in the use of mineral fertilizer in winter wheat caused by implementation of national action plans and estimate the yield effects of reduced standard N rates.

2 MATERIALS AND METHODS

Figures for rates of mineral fertilizer and animal manure were obtained from the KVADRATNET, which is a square grid of 7×7 km established by the Danish Agricultural Advisory Service (DAAS) in the winter 1986/87 to provide annual estimates on the content of mineral soil N in the spring. This systematic grid has 590 intersections on farmland. Each intersection is represented by a 50×50 m area managed by the farmer, who also annually reports on manure and fertilizer applications. The data was considered as useful for this purpose, although Heidmann et al. (2001) drew attention to elements of uncertainty associated with the reporting.

The KVADRATNET data consist at present of 3300 observations on winter wheat. We selected those that had the most important preceding crops (cereals, sugar beet, rape or peas) and where the dominating soil type was sandy loam. The data did not give us the opportunity to distinguish between ordinary wheat for feeding and wheat for bread, where the latter may allow a higher N rate to be applied. Bread wheat accounts for <10% of the area with winter wheat, and has a supplemental standard N rate of 30 kg N/ha. The remaining data were divided into two sets: (A) exclusive fertilization with mineral fertilizer N, and (B) fertilization with animal manure plus mineral fertilizer N (Table 1).

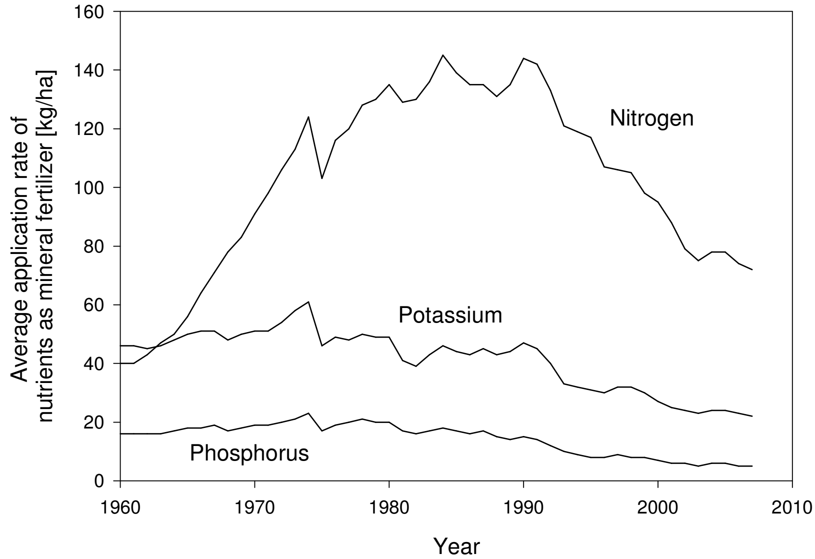

FIGURE 1 **Average application rate of N, P and K in Danish agriculture from 1960-2007 (Grant et al., 2007; The Danish Plant Directorate, 2006).**

Several changes in agricultural systems have taken place over time (e.g. area with winter wheat, livestock holdings and crop rotation), which adds noise to data and causes considerable variation. In a crop rotation including winter wheat, an intersection point may be redrawn systematically at intervals of 3-4 years, but as the crop preceding winter wheat more frequently has become winter wheat since the middle of the 1990s, which indicates continuous cropping, the systematic redrawing has increased. This causes correlated data that may be considered as repeated measurements, and analysis on sub-datasets of intersection points redrawn ≥10 times may be more suitable to estimate changes over time as some random variation may be excluded. The datasets sub-A and sub-B reflect the typologies of winter wheat crops fertilized with mineral fertilizer only and with a combination of animal manure and mineral fertilizer, respectively (Table 1).

To get the advantage of the repeated measurements we focus on the sub-datasets that both represent sandy loam soils but in two different regions of the country (Table 1). Considering the effect of reduced standard N rate we focus on the changes comparing two periods: the past, from the beginning of the 1990s to 2000 (some variation in the starting year used depending on the dataset) *versus* today, the period 2001-06 (reduced standard N rates corresponding to *c.* 90% of the standard N rates).

TABLE 1 **Overview of the datasets extracted from the KVADRATNET database for winter wheat.**

	Dataset A Mineral fertilizer N exclusively	Dataset B Animal manure plus mineral fertilizer N
No. of observations	1374	1103
No. of intersection points	389	311
Sub-dataset *	Sub-A	Sub-B
No. of observations	190	190
No. of intersection points/county	16 / Zeeland	17 / Jutland

* More than nine recordings of individual intersection points

Estimates of yield effects are based on 115 field experiments on N response carried out by DAAS during 1998-2007 using application rates from 0-250 kg N/ha in six steps of 50 kg N/ha. The preceding crops were cereals or fallow with a maximum annual animal manure N rate of 40 kg/ha in the preceding five years. The yield response of each individual experiment was estimated using a modified cubic polynomial function with plateau when the first inflection point was passed. Where a cubic function did not fit, a quadratic function was used. The experiments were all located in well-managed fields including pesticide treatments following the practice of the surrounding fields. The varieties used in these experiments reflect the current market assortment incorporating the increased yield potential achieved through breeding.

3 RESULTS AND DISCUSSION

3.1 Change in application rate of mineral N, P and K

Farmers using animal manure for winter wheat, particularly pig slurry applied by trailing hoses in the spring, have recognised the nutrient value of animal manures, and they consider these nutrients in the fertilizer planning. Today, the use of mineral N fertilizer has been reduced by more than 50%, from *c.* 160 to 70 kg N/ha on average (Figure 2). The N rate for farms exclusively using mineral fertilizer was on average of *c.* 170 kg N/ha for the full dataset A with a minor decline after the introduction of reduced standard N rates. Animal manure is not exclusively an N source as other nutrients are applied with the manure. The change in the use of animal manure due to statutory orders on N therefore also affects the application of other nutrients.

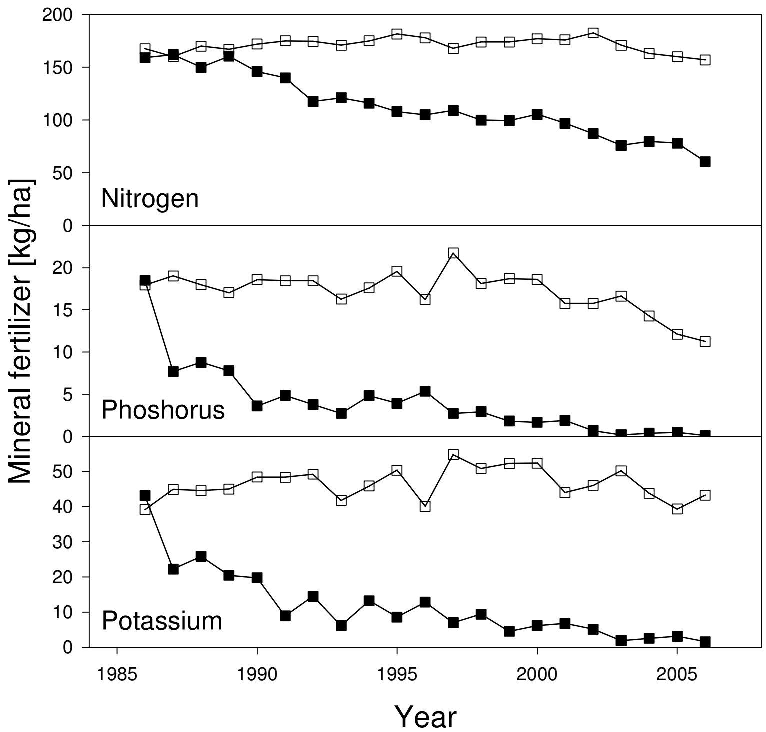

FIGURE 2 **Average rates of mineral fertilizer N, P and K applied for winter wheat. Farmers exclusively using mineral fertilizer (□) and farmers using mineral fertilizer in addition to animal manure (■) based on datasets A and B, respectively (Table 1).**

Farmers' also accounts on P and K in animal manure and dataset B (Table 1) clearly show a reduced application rate of P and K in mineral fertilizers (Figure 2). The reduced use of mineral fertilizer is enhanced as animal manure is often used for winter wheat, partly due to the increased area of winter wheat since the mid 1980s (Petersen & Kristensen, 2010), and partly due to a more even distribution of the animal manure between crops within the crop rotation as indirectly requested by the statutory orders. For farmers using exclusively mineral fertilizer (Dataset A, Table 1), some reduction in mineral P fertilizer was also observed (Figure 2). In contrast, the application rate of mineral K was largely unchanged during the period 1985-2006 at 46 kg K/ha on average.

3.2 Yield effect of reduced standard N rate

In the sub-datasets random variations due to general structural changes in the agricultural sector were excluded and the data are considered as repeated measurements. For intersection points without application of animal manure the mineral fertilizer N rate changed from 182 kg N/ha as an average for the years 1991-2000 to 166 kg N/ha (corresponding to -9%) as an average for 2003-06 using sub-dataset A (data not shown). Using purely the 115 DAAS response curves without taking any other aspects on N fertilization into account, the difference between the past and present pair-wise yield estimates was 1.4 dt/ha (s.e. 0.87 dt/ha). If animal manure is included (sub-dataset B) the question becomes more complicated as there have been several changes in the substitution rate for N for different types of animal manure plus changes in requirements regarding application time and method to prevent over-application of animal manures (Petersen & Knudsen, 2010). In addition, Petersen & Knudsen (2010) estimated an average yield loss of 1.2 dt/ha due to traffic damages caused by slurry application in the spring, plus some minor effects of the use of legislated standard N rates.

4 CONCLUSIONS

Implementation of statutory orders on the agricultural use of animal manure and increased focus on nutrient utilization and cycling in agricultural systems has reduced the application rates of N, P and K in mineral fertilizer considerably. In total an effect of legislation on N rate/fertilization was estimated in the range 3.7-4.3 dt/ha, but this yield loss was only able to explain a minor part of the stagnating yields in winter wheat. Effects on winter wheat grain yield due to changes resulting from nutrients other than N were not demonstrated.

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