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The relevance of spatial scales in nutrient balances on dairy farms

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ABSTRACT

Policy makers and farmers use tools, such as a nutrient balance, to gain insight into the environmental impact of agricultural practices. A discrepancy, however, exists between the needs of policy makers and farmers, about the use and the spatial scale of such tools. Farm balances calculate nutrient balances across all agricultural fields within a farm without distinguishing separate fields, whereas field balances calculate a nutrient balance on a delineated field. For farmers, a nutrient balance at field level is more useful than at crop or farm level, because decision making and fine-tuning management occurs at the field level. A field balance, however, requires more detailed data than a farm balance and therefore is less easy to implement. As soil types influence nutrient balances, we hypothesize that if within-farm variation in soil types is low, there is no need to replace a farm balance by a field balance. To test this hypothesis, we computed nutrient balances at farm and field level on five Dutch dairy farms (three on sand, two on clay), varying in degree of within-farm variation in soil series. A full year of soil nitrogen (N) and phosphorus (P) input and output data on farm and field level were provided by farmers, while soil variation was determined using the Dutch 1:50.000 soil map. The Annual farm Nutrient Cycle Assessment (ANCA) was used to calculate soil N and P surpluses, and soil nutrient fluxes such as nitrate leaching and nitrous oxide emission at farm and field level. Even on farms with few soil series, a considerable variation in N and P inputs, outputs and balances across fields was found, due to management differences and soil properties not represented by the soil map. Furthermore, field-level balances better represented nitrogen leaching than farm-level balances on farms with diverse soils (reflected by different leaching factors) and negative nitrogen field balances (deficits). Also, using field balances, for one case study farm the highest soil N surplus (kg ha^{-1}) was found on grass fields with the highest risk of N leaching. A field balance, therefore, provides more meaningful information than a farm balance when variation in soil types and/or management factors is found within the farm, because soil types and management factors affect N and P balances, N leaching and N emissions. For farms with the highest variation in soil types and/or management, we recommend using field-level nutrient balances in order to detect extreme surpluses, deficits, leaching and/or emissions, to improve management decisions.

1. Introduction

The sustainable development goals (United Nations, 2017) address the dual-challenge to produce enough food to feed a growing and more prosperous population, and to produce this food in an environmentally friendly way. The current food production system, however, has a major impact on the environment. Livestock production in Europe, for example, is responsible for about 80% of soil acidification and air pollution (via emission of mainly ammonia and nitrogen oxides), and for 73% of the water pollution (via leaching of nitrate or phosphate) (Leip et al., 2015). To reduce emissions to soil, air and water, the European Union introduced the National Emission Ceilings Directive to reduce air pollutants, and the European Nitrates Directive to reduce ground- and surface water nitrogen (N) and phosphorus (P) concentrations (European Commission, 1991; European Environment Agency, 2017). To reach the targets, policy makers and other actors need tools to monitor the environmental impact of agricultural practices at farm level.

Nutrient balances can be used as a policy tool (Sassenrath et al., 2013). For farmers, who manage the land field by field, nutrient

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balances at field level are more useful than at crop level (all fields within a farm with the same crop) or farm level (the whole farm: land, housing and animals), because decision making and fine-tuning management occurs at the field level (Van Beek et al., 2003). A nutrient balance at field level, however, would require more data than a balance at crop level or farm level and, therefore, is less easy to implement (Öborn et al., 2003). Defining a nutrient balance at crop or farm level assumes that nutrient balances and associated losses are equal across fields. For example, the Overseer model (Thomas et al., 2005) used leaching and emission factors specific for farming systems, but on the national level, and the Annual farm Nutrient Cycle Assessment (Aarts et al., 2015) used field-specific leaching and emission factors that were aggregated to the crop and farm level. Nutrient balances vary between fields due to differences in soil characteristics (soil compaction or the depth and the soil organic matter content of the A horizon), hydrological conditions, grazing regimes, fertilizer applications and crop yields (Lipiec and Stępniewski, 1995; Oenema et al., 2010; Van Es et al., 2006). A discrepancy, therefore, exists between the needs of policy makers and farmers, about the use and the spatial scale of the tools that are used to quantify the environmental impact of agricultural practices.

Furthermore, the effect of soil characteristics (such as soil compaction, depth of the A horizon, and groundwater tables) on the nutrient balance is often excluded despite the fact that soil processes, such as denitrification and the build-up and decline of soil organic matter, are included in nutrient balances (e.g., Van Beek et al. (2003) and Watson and Atkinson (1999)). Van Beek et al. (2009) assessed soil nutrient balances on three dairy farms located on well-drained sand, and poorly-drained clay and peat in the Netherlands. They found that average denitrification rates were highest for peat and clay and lowest for sand. Average N leaching was highest for sand and lowest for clay. P surplus, however, was highest for peat and lowest for sand and clay. The presence of soil organic carbon and water content stimulate denitrification (Van Beek et al., 2003). Soil texture, groundwater depth and precipitation regulate N leaching, and texture, groundwater depth, the presence of iron and aluminum (hydr)oxides and the P content of the soil regulate the soil P adsorption capacity and P leaching (Freese et al., 1992; Oenema et al., 2004; Schoumans et al., 2013). Even within the soil type classes 'sand', 'clay' and 'peat', soils vary considerably (e.g., in texture, soil organic matter and groundwater depth), thereby affecting local nutrient balances. This illustrates that more detailed descriptions of soils are important to consider in nutrient balances, rather than using these broad soil type classes.

We hypothesize that if within-farm variation in soil types (combination of texture, groundwater table, depth of the A horizon) is low (Fig. 1A), there is no need to replace a farm balance by a field balance. Unless manure application rates vary highly across fields within a crop type on a specific soil series, we expect similar biomass yields, N and P balances, N leaching and N emissions on those fields. Yet if within-farm soil variation is high (Fig. 1B), a nutrient balance at crop or farm level may not be a good representation of the various nutrient balances at field level. The objective of this paper is to test the above hypothesis and to assess whether it is relevant to calculate a nutrient balance at field rather than at crop or farm level, given any soil variation within a farm. Since January 2017, dairy farmers in the Netherlands are required to use Annual farm Nutrient Cycle Assessment (ANCA, in Dutch: Kringloopwijzer), in an attempt to improve nutrient use efficiency at their farm and to reduce nutrient losses to the environment (Aarts et al., 2015). We therefore used ANCA to calculate N and P balances at field, crop and farm level, and estimate N leaching and N emissions, using five case study dairy farms.

2. Materials and methods

2.1. Farm and soil characteristics

We selected five dairy farms that take part in the ongoing project 'Cows and Opportunities' (in Dutch: 'Koeien & Kansen'). This project monitors soil nutrient input and output data at field level, which is used in the present study to calculate nutrient balances at field, crop and farm level (Oenema et al., 2001). We used nutrient balances at the field level for 2014.

The selected five dairy farms in the Netherlands were experimental Farm SHo (Farm 'De Marke', sand, homogeneous), and four commercial pilot farms which will be referred to as Farm SHe1 (sand, heterogeneous 1), Farm SHe2 (sand, heterogeneous 2), Farm CHe (clay, heterogeneous) and Farm CHo (clay, homogeneous; Fig. 2). Selection criteria included soil texture (either mainly on sand or clay) and within-farm spatial variation in soil series (the number of soil series on the Dutch 1:50.000 soil map). Farm SHo and CHo had the lowest number of soil series (four each) and were classified as homogeneous (Fig. 2, Table 1). For both farms, 80% of the farmland was located on two main soil series. Farm SHe1, She2 and CHe were classified as heterogeneous farms in terms of soil series, as Farm She1 and CHe had eight soil series, and Farm SHe2 had ten soil series (Fig. 2, Table 1). Land of farm SHe2 was most equally distributed across the various soil series; each soil series had a surface area of 1–17% of the land. About 43% of the land of Farm SHe1 was located on two main soil series, and only 2–16% on the remaining six soil series. About 63% of the farmland of Farm CHe was located on the two main soil series, and between 4–14% on the remaining six soil series.

Farm SHo was located on aeolian cover sands. The dominant soil series of the four soil series present within this farm was the *'veld' podzol* soil (ordinary hydropodzol, Table 1), which covered 46.4 ha of the total 54.5 ha (Fig. 2A, Table 1). About 80% of the farmland was in grass-maize rotation in 2014. As Farm SHo is an experimental farm (Knowledge Transfer Centre De Marke, 2017), most data were based on

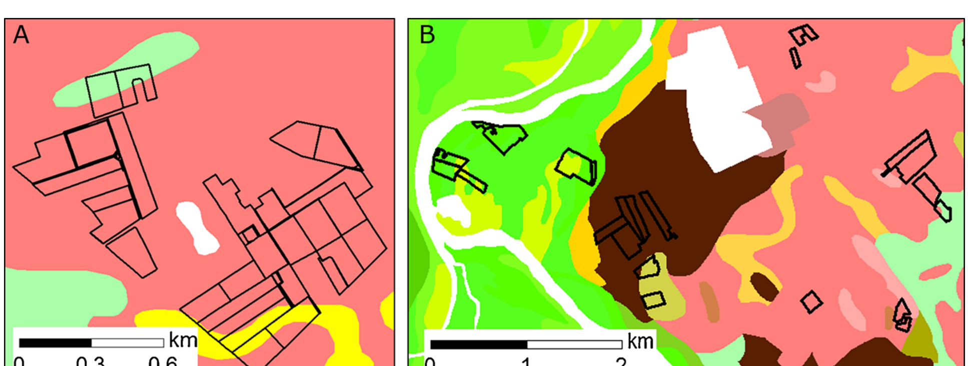

Fig. 1. Example of two farms on a 1:50.000 soil map, each colour depicts a soil series. Black lines delineate fields belonging to one farm. A) variation in soil series is low: 'homogeneous'; B) variation in soil series is high: 'heterogeneous' (See Section 2.1 for more information of about the farm and soil characteristics).