SOIL TESTING, NUTRIENTS AND SOIL QUALITY

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INTRODUCTION

Soil quality is the result of physical, chemical and biological soil processes and their interactions. Soil quality has been defined as 'fitness for use' (Pierce and Larson, 1993). Following this definition, soil quality may refer to very different sets of properties, depending on environmental conditions (climate, soil type) land use, farm type and management. The valuation of particular soil traits also depends on awareness by land managers and policy-makers, and on the functions these actors expect from soils, including the avoidance of environmental risks. Stockdale *et al.* (2018) gave an overview of soil functions required by society and/or land users (Table 1.)

Table 1. Some soil functions required by society and/or land users (Stockdale *et.al.*, 2018)

Production of agricultural, horticultural or forestry products
Regulation of water quantity and quality (e.g. nitrate, phosphate, pesticides, metals, microorganisms)
Regulation of atmospheric composition (e.g. nitrous oxide, methane, carbon dioxide)
Reservoir of biodiversity
Cycling of elements (e.g. C, N, P, K, S)
Waste disposal pathway – detoxification of pollutants
Foundation of buildings, roads, pipelines

SOIL QUALITY AND TESTING

Bünemann *et al.* (2018) reviewed publications and assessment tools with respect to soil quality indicators and showed how the objectives changed over the years from a focus entirely on crop production towards a more multifunctional approach, involving a broader set of end-users/stakeholders. (Figure 1).

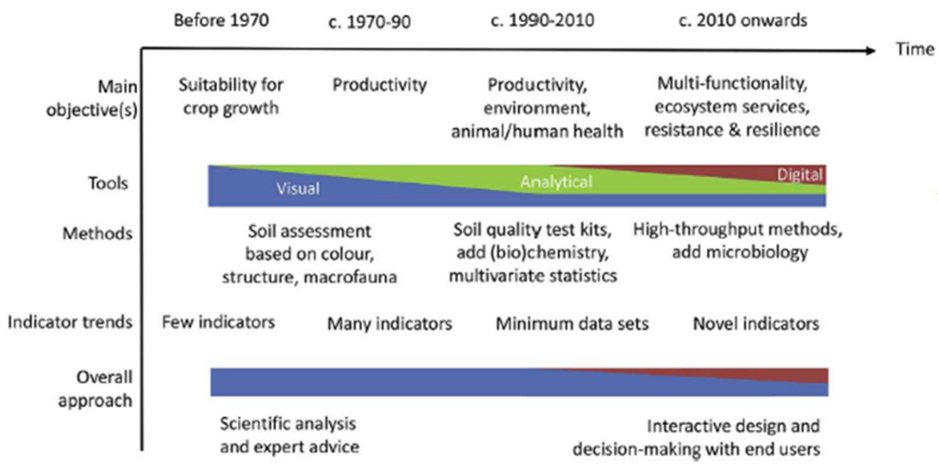

Figure 1. Objectives, tools and approaches of soil quality assessment through history (Bünemann *et al.*, 2018).

The same authors also reviewed 65 indicator sets for soil quality under agricultural land use. They observed that total organic matter/carbon and pH are the most frequent used soil quality indicators followed by available phosphorus (P), various indicators for water storage and bulk density. Also texture, available potassium (K) and total nitrogen (N) are frequently used. Among biological parameters, relevant indicators were earthworms (number; biomass), N mineralisation, microbial biomass and soil respiration.

NUTRIENT CYCLING IN GRASSLAND SYSTEMS

Compared to an arable farming system, grassland-based systems are quite complex. Grass is grazed by livestock but is also conserved as silage or hay for winter or dry periods. Grass and conserved forage are main components in the feed ration, complemented by purchased concentrates and other feeds, and manure or slurry is returned to the field. The net outputs from this leaky cycle are usually milk, meat and/or wool. To make up for nutrient offtake in these products and to substitute for losses, supplementary mineral fertilisers are used. For nitrogen, biological fixation by legumes may constitute an additional input term on the nutrient balance. Nutrients are temporarily stored in the soil, to be released again via mineralisation and other bio-chemical processes. Grass-based farming systems are 'circular systems'. One of the first authors to note this (Figure 2) was Ryden (1982).

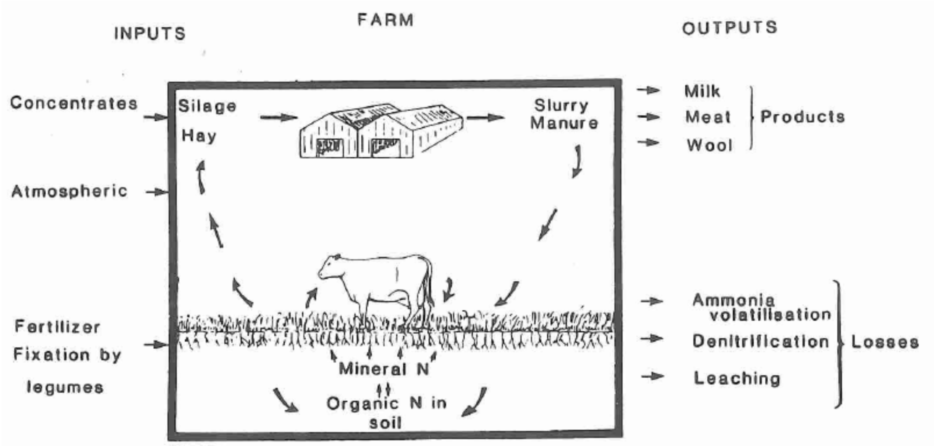

Figure 2. Schematic representation of nitrogen flows in a grassland-based farming system (Ryden, 1982).

Experimental farm De Marke was initiated in 1992 (Verloop, 2013) to study this cycle on a site that represents typical farming conditions on sandy soils in the Netherlands (= 40 % of Dutch Agriculture area). Its chief aim was to develop and demonstrate management options to reconcile farm economy with environmental goals.

Over the years, the conversion efficiency of net (i.e. after subtraction of ammonia losses) soil N input to gross feed production increased from 65 (1993-1999) to 81% (2004-2008); for P, this efficiency increased from 94 (1993-1999) to 115 % (2004-2008). The N surplus on the soil surface balance then amounts to 58 kg ha^{-1}, which corresponds to a nitrate concentration in the groundwater of 52 mg l^{-1}, close to the legal target value (Verloop, 2013). Since 1999, 17 commercial Dutch pilot farms joined in the 'Cows & Opportunities' project (Oenema, 2013) to test these outcomes from the De Marke. Between 1998 and 2011 they reduced average nutrient surpluses by 33% (N) and 53% (P), while surpluses on the 'average' commercial farm decreased by 29% (N) and less than 28% (P). Nutrient use efficiency on the pilot farms increased to 38% (N) and 85% (P), surpassing gains

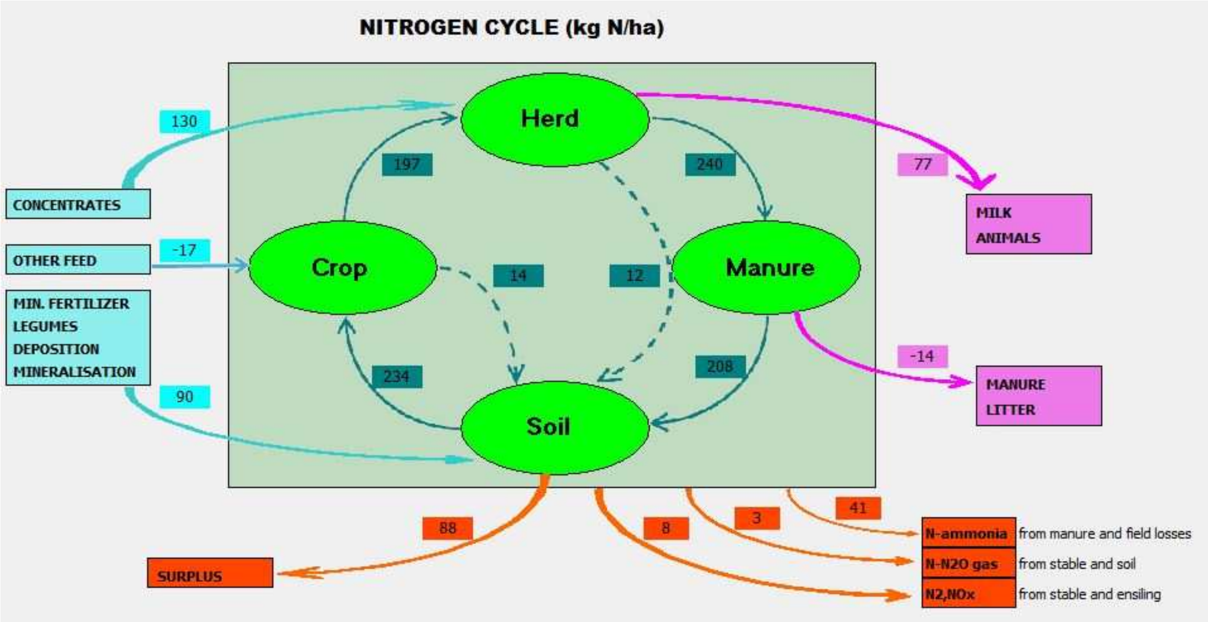

Figure 3. Main nitrogen flows on a grassland-based dairy farm; De Marke – 2014 (Oenema, unpublished data).

of 30%, (N) and 60% (P) typically achieved on commercial farms (Oenema, 2013). The next step was the development of the Annual Nutrient Cycling Assessment tool (ANCA) (Aarts *et al*., 2015; Oenema and Korevaar, 2019). This tool quantifies nutrient performance on commercial dairy farms. Improved nutrient cycling increases input use efficiency, reducing both monetary cost and harmful emissions. The ANCA model includes four components: herd management, slurry storage and handling, soil management, and crop production (Figure 3) and specifies internal flows and net in- and outputs. ANCA is a mandatory management tool since 2016 for all Dutch dairy farms. Milk collectors will soon refuse milk from farms not using ANCA (Oenema and Korevaar, 2019).

IMPACT OF MINERAL FERTILIZER ON SOIL ORGANIC CARBON

Fertilizer inputs (N, P, and potassium, K) affect aboveground production, but also belowground biomass input and soil organic carbon (SOC) stocks. Poeplau *et al.* (2018) studied the impact of mineral fertilizer use on the SOC in seven long-term grassland experiments (16-58 years) in Germany and the Netherlands. PK and NPK fertilization had a significant positive effect on SOC stocks in the topsoil (0-30 cm depth). In treatments receiving all macronutrients (N, P, K), 1.15 kg of N was needed per kg of SOC gained. In a second study, Poeplau *et al.* (2019) showed that increased microbial carbon use efficiency (CUE) due to mineral fertilizer use contributed to the build-up of SOC. The authors found that microbial CUE was increased by NPK input at the two sites where this indicator was studied, compared to the unfertilized control. This was due to both an increased growth and a decreased respiration. Increased C input alone could not explain observed SOC stock changes under NPK fertilization. Hence, fertilization not only influenced C input, but also its fate in the soil.

DISCUSSION AND CONCLUSION

Among the numerous soil quality indicators known, soil organic matter/carbon, pH, bulk density texture and water holding capacity are the most commonly cited according to a recent review, followed by the respective availabilities of macronutrients N, P and K. Whereas management can shift the above physical properties within a limited range only, grassland systems offer many ways to optimise 'nutrient indicators' such as nutrient stocks, balances and losses. Considerable gains have recently been made in N and P use efficiency at farm level in the Netherlands, reducing costs and losses to the environment. Alongside this, it has been shown that fertiliser inputs may have a positive impact on microbial carbon use efficiency, and thereby on carbon sequestration in the soil.

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REFERENCES

Aarts H.F.M., De Haan M.H.A., Schröder J.J., Holster H.C., De Boer J.A., Reijs J.W., Oenema J., Hilhorst G.J., Sebek L.B., Verhoeven F.P.M. and Meerkerk B. (2015) Quantifying the environmental performance of individual dairy farms – the annual nutrient cycling assessment. *Grassland Science in Europe,* 20, 377-379.

Bunemann E.K., Bongiorno G., Bai Z., Creamer R.E., De Deyn G., De Goede R., Fleskens L., Geissen V., Kuijper T.W., Mäder P., Pulleman M., Sukkel W., Van Groenigen J.W. and Brussaard L. (2018) Soil quality - a critical review. *Soil Biology and Biochemistry,* 120, 105-125.

Oenema J. (2013). *Transitions in nutrient management on commercial pilot farms in The Netherlands*. Thesis Wageningen University, pp. 198.

Oenema J. and Korevaar H. (2018). *Closing Nutrient Cycle: the Dutch way*. EuroDairy workshop January 24-25th 2018, Vught (The Netherlands). EuroDairy report, Wageningen University & Research

Pierce F.J., Larson W.E. (1993). Developing criteria to evaluate sustainable land management. In: J. M. Kimble (ed), *Proceedings of the Eighth International Soil Management Workshop: Utilization of Soil survey Information for Sustainable Land Use*. USDA Soil Conservation Service, National Soil Survey Center, Lincoln, NE, p. 7-14.

Poeplau C., Helfrich M., Dechow R., Szoboszlay M., Tebbe C.C., Don A., Greiner B., Zopf D., Thumm U., Korevaar H. and Geerts R. (2019) Increased microbial anabolism contributes to soil carbon sequestration by mineral fertilization in temperate grasslands. *Soil Biology and Biochemistry*,130, 167-176.

Poeplau C., Zopf D., Greiner B., Geerts R., Korevaar H., Thumm U., Don A., Heidkamp A. and Flessa H. (2018). Why does mineral fertilization increases soil carbon stocks in temperate grasslands? *Agriculture, Ecosystems and Environment*, 265, 144-155

Ryden J.C. (1984) *The flow of nitrogen in grassland.* Proceedings The Fertiliser Society 229, London pp 44.

Stockdale E., Griffiths B., Hargreaves P., Elphinstone J. and Bhogal A. (2018) *Developing a practical and relevant soil health toolkit for UK agriculture*. Proceedings International Fertiliser Society 824, pp 28.

Verloop K (2013) *Limits of effective nutrient management in dairy farming: Analyses of experimental farm De Marke.* Thesis Wageningen University, pp. 192.