Agricultural Systems 139 (2015) 82–92

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Nitrogen soil surface balance of organic vs conventional cash crop farming in the Seine watershed

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ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form 29 May 2015
Accepted 16 June 2015
Available online xxxx

Keywords:
Nitrogen
Nitrate
Organic farming
Soil surface balance
Surplus
Fertilization

ABSTRACT

In major cash crop farming areas like those of the Paris basin, nitrogen surpluses related to the synthetic fertilization of arable soils are the main cause of severe nitrate contamination of the groundwater and river network. Based on farmer interviews and the Nitrogen Soil Surface Balance integrated at the scale of the entire crop rotation cycle, we assessed the current agronomical and environmental performance of 68 organic rotations (with or without livestock) and compared them with those of the dominant conventional crop rotation in the same pedoclimatic areas. We demonstrated that, compared to conventional systems, organic cropping systems receive 12% less of total N inputs (including legume symbiotic fixation) without significant reduction in N yield. Consequently, the N surplus is 26% lower in organic than in conventional cropping systems. Forage legumes are the key component of the organic cropping systems studied, accounting for around 70% of total N inputs and for 52% of N yield. Therefore, the extension of organic farming to a broader scale to reconcile water quality and food production will substantially depend upon local opportunities of valorizing legume fodder cereal by-products. We also evidenced that the provisional N balance approach that has been promoted in the Nitrate Directive does not guarantee the infiltration of sub-root water fluxes meeting the drinking water standard of 11 mg N.l^{-1} without a downward revision of yield objectives.

1. Introduction

Agricultural areas of the Seine watershed (81,000 km^2) are specialized in intensive crop farming (cereals, oilseed rape, sugar beet), mostly sustained by synthetic fertilizers, while animal husbandry has been concentrated within the adjacent West and North regions. This spatial disconnection between crop cultivation and animal farming was made possible by the advent of the Haber–Bosch industrial N_2 fixation process. Nowadays, in addition to providing most plant products consumed by the Paris agglomeration, the Seine basin, traditionally France's breadbasket, exports 80% of its huge cereal production on international markets, but on the other hand imports most of its population's animal protein requirements (Billen et al., 2012). These modern industrial agrosystems cause severe surface and groundwater contamination with pesticides and nitrates, thus endangering drinking water resources and leading to eutrophication problems in coastal marine areas, with considerable social costs (Bommelaer and Devaux, 2011; Thieu et al., 2011). Inadequate implementation of the EU Nitrate Directive 91/676/CEE (European Council, 1991) to protect surface and groundwater from agricultural N pollution has resulted in France being convicted several times by the European Court of Justice. The whole Seine Basin, with intensive crop production, has been classified as a vulnerable zone, because 68% of its drinking water intakes are contaminated by pesticides and 30% by nitrate (AESN, 2013). To meet the Commission's expectations, France undertook a reform set by two interdepartmental decrees (MEDDE, 2013), forming a regulatory basis composed of eight measures applicable across the vulnerable zones. The core component of this new regulation is to achieve balanced fertilization based on the provisional mineral nitrogen balance, outlined by the French Committee for the Study and the Development of Rational Fertilization Practices (COMIFER). While, a broad consensus exists among practitioners from the agricultural sector on the merits of such mandatory decision-making support tools for nitrogen fertilization, some voices, however, call for a more radical change of the agricultural system toward new land use objectives favoring grasslands and ecosystem-based approaches such as organic farming (OF). With long and diversified crop rotations and the absence of synthetic fertilizers and pesticides, OF appears to be an alternative to the conventional farming (CF) input-intensive model to restore and protect water quality, and as such OF is recommended in the EU Water Framework Directive 2000/60/EC

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(European Parliament, 2000). While positive effects on pesticide contamination are obvious, lively debate continues on N issues:

(i) *N leaching* - The main concern is the timing of N mineralization vs. crop N demand, and temporary grassland plowing that can produce a considerable flush of N leaching (Kelm et al., 2008; Eriksen et al., 2004; Stopes et al., 2002). Most studies, comparing leaching in OF and CF show that leaching rates per ha are lower (30–50%) on organic than on conventional fields (Benoit et al., 2014; Stopes et al., 2002; Haas et al., 2002; Honisch et al., 2002; Stolze et al., 2000; Hansen et al., 2000; Korsaeth and Eltun, 2000; Berg et al., 1999; Reitmayr, 1995), although some authors found around 20% more leaching in OF than it has been measured in CF (Sapkota et al., 2012; Kelm et al., 2008; Torstensson et al., 2006; Kristensen et al., 1994). When the leaching rate is expressed per unit of output, results are more mixed, slightly lower leaching rate in favor of OF (Benoit et al., 2014), non-significant differences (Mondelaers et al., 2009; Kirchmann and Bergström, 2001), or disfavor OF (Korsaeth, 2008).

(ii) *Soil fertility* (Stockdale et al., 2002) and long-term *sustainability* related to the dependence of organic systems to nutrients coming from the conventional agro-industry, through imported feedstuffs, beeding, manure, meat-and-bone meals, beetpulp residues … (Nowak et al., 2013; Goulding et al., 2009).

(iii) *Productivity* of organic farming systems with contrasted results depending on whether individual crops or full rotations are compared (Connor, 2013; Kirchmann et al., 2008; Ponisio et al., 2015; Seufert et al., 2012).

The above issues are linked to nutrient management strategies that fundamentally differ between conventional and organic farming. Indeed, OF shifts the emphasis away from inorganic plant-available pools to the total organic and mineral reservoirs that can be accessed through microbial and plant-mediated processes (Drinkwater and Snapp, 2007). Crop rotations are a lynch-pin of OF systems to build/maintain soil fertility, and also to control pests, diseases and weeds (Stockdale et al., 2001), therefore N management must be analyzed over periods of longer than a growing season of a single crop (Watson et al., 2002a). N budgeting (farm-gate and soil surface) approaches are increasingly used by scientists and policy makers to assess nutrient use efficiency, long term sustainability and environmental impact of a wide range of farming systems at different spatio-temporal scales (Lassaletta et al., 2014; de Vries et al., 2011; OECD, 2008; van Beek et al., 2003; Oenema et al., 2003; Scoones and Toulmin, 1998). The farm gate method considers the farm as a “black box” and thus does not show the internal flows between livestock and crop production activities. On the other hand the SSB is a way to explore the relationships between the mean harvested yield (Y), including the harvested fodder and grazed grass consumed by the livestock, and total N inputs to cropland (totNinp) by synthetic and organic fertilizers, grazing excreta, atmospheric deposition, and biological nitrogen fixation (BNF). Specifically regarding OF, most studies in EU used farm gate balance method to examine N surplus/deficit and N use efficiency in mixed crop and livestock farms, mainly dairies. They show varying results depending in particular on livestock density and the estimation of biological nitrogen fixation from legumes fodders and crops (Dalgaard et al., 2012; Nielsen and Kristensen, 2005; Steinshamn et al., 2004; Watson et al., 2002b; Cederberg and Mattsson, 2000; Simon et al., 2000; Halberg et al., 1995). Studies comparing organic and conventional systems via the SSB method are scarce but they tend to show that OF systems had the lowest soil N surplus (even sometimes negative indicating soil depletion or an underestimation of nitrogen fixation) and a better N use efficiency in comparison with the CF systems (Migliorini et al., 2014; Blesh and Drinkwater, 2013; Berry et al., 2003; Eltun et al., 2002). In the major cash crop farming areas of the Paris basin, OF, which represents less than 2% of the agricultural land use (ALU), is clearly understudied, and therefore the controversy feeds on the gap in current knowledge.

The principal aims of this study were to acquire knowledge on OF systems in the North of France, by assessing the agro-environmental performances of 53 farms, covering a wide range of practices, and comparing them with the dominant CF systems following the recent mandatory fertilization practices set by the French application of Nitrate Directive. This assessment was primarily based on the SSB method extended over the entire crop rotation cycle, using data collected through farmer's interviews and from agricultural statistics.

2. Material and methods

2.1. Current agricultural profile of the Seine watershed in Northern France

The Seine watershed extends over 76,200 km^2 in a large sedimentary area dominated by limestone, clay and chalk formations arranged in concentric rings around Paris, and covered by a thick layer of fine eolian loam in the western and central part. The climate is oceanic and temperate (12 °C mean temperature), with a regular distribution of precipitations throughout the year but higher evapotranspiration in summer, resulting in high water discharge in winter and low water in summer. Land use is largely dominated by arable land, which covers 53% of the watershed (Corine Land Cover 2006, http://www.epa.ie/whatwedo/assessment/land/corine/) (Fig. 1a), with winter wheat as the dominant crop (29% of the agricultural land use, ALU). Grasslands, extending over 9.8% of the basin, are mainly located in the periphery in the Normandy and Morvan regions. Livestock densities are quite low in the central part of the Seine basin, while animal farming is much more developed in the northwestern part of France (Fig. 1b).

Organic farms in the area studied represent less than 2% of the ALU. The French agency for the development and promotion of organic farming (Agence Bio) kindly made available an anonymous census of 7334 organic farms located in the northern part of France, with their location, size and production system in 2010. Among these organic farms, 40% had livestock production and 62.4% of them also grew cereals and grain legumes. Most of them had beef and/or dairy cattle farms (75%), followed by poultry (21.9%), sheep (12.6%), and pigs (7.2%). What is striking is that those livestock husbandry activities were mainly concentrated in the western (Brittany, Normandy, Pays de la Loire) and northern parts of the Paris basin (Nord-Pas-de-Calais), and somewhat in the eastern periphery, whereas the center of the basin was nearly devoid of livestock activities (Fig. 1d). In departments were livestock is concentrated, the density can reached 1.8 livestock unit (LU)/ha, which implies manure emissions close to the limit of 170 kgN ha^{-1} yr^{-1}cc imposed by the European regulation (CE no 889/2008 Art. 3). Thus, surprisingly, organic farming in the area studied closely follows the same trend of specialization as observed in conventional farming (Fig. 1), namely a strong decoupling of crop and animal farming. This was already observed by Petit (2013) for the Ile-de-France region and is explained by the distribution of the commercialization opportunities. It should be noted, however, that the proportion of the agricultural land use under permanent grassland is greater in organic farms (Fig. 1a,d). Finally, 28.4% of the farms listed were specialized in field crops (mostly legumes and cereals). They were evenly distributed in the area studied, but their size was highly variable, with a mean of 70.7 ± 73 ha and a maximum of 582 ha.

2.2. Constitution of a sample of organic farms and comparative conventional systems

The organic farms selected for detailed inquiry into their agricultural practices covered a wide gradient of pedoclimatic conditions and farm types ranging from short rotations dedicated to cash crops with high amounts of organic fertilizers to highly diversified rotations including