Nitrogen use efficiency and carbon footprint of an agroecological dairy system based on diversified resources

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Abstract

A mixed crop-dairy system named OasYs, based on temporary grasslands and on the grazing of diversified forage resources, was implemented in 2013 (Lusignan, France) in a plain area affected by summer droughts. Conducted without irrigation and with limited inputs, this agroecological system aims to permit farmers to live from their dairy system in a context of climate change, while preserving environment and contributing to animal welfare. We present the nitrogen (N) balance and use efficiency, and the carbon (C) footprint of this system assessed by the CAP'2ER tool over 2017-2020. OasYs showed small average N surpluses (47 kg N ha^{-1} UAA) and good N use efficiency (49%). Greenhouse gases (GHG) gross emissions expressed in kg CO_2-equivalent per litre of corrected milk decreased from 2017 (0.90) to 2020 (0.78). They were lower compared to other grassland-based systems from lowland areas. These results can be explained by the sharply reduced use of N fertiliser and concentrates counterbalanced by a large use of legumes and a new breeding strategy. The net C footprint of milk is however higher than the average of grassland-based systems from lowland areas, because of lower soil C storage resulting from the ploughing of temporary grasslands.

Keywords: mixed crop-dairy system; agroecology; grazing; legumes; OasYs

Introduction

In order to face the current challenges of dairy farming in north-west Europe, a mixed crop-dairy system was designed to permit farmers to live from their dairy system in a context of climate change, while preserving environment and contributing to animal welfare.
This cattle system named OasYs (Novak *et al.*, 2018) is based on the principles of agroeocology (Dumont *et al.*, 2014) and it relies on the grazing of diversified forage resources, comprising mainly multispecies temporary grasslands but also annual crops. The originality of this system is to test several innovations both on the forage system (*e.g.* grazing of annual crops and fodder trees, large use of legumes) and on the livestock system (*e.g.* three-way crossbreeding, extension of lactation length), and to integrate them into a consistent way at the farm level. The whole farming system was redesigned to address together the challenges of adaptation and mitigation to climate change while allowing for the delivering of other ecosystem services. We hypothesise that a greater diversity of the dairy system's components and of their functions will both improve the resilience of the overall system against climatic hazards, and permit high production levels and environmental performance. This paper presents the N balance, GHG emissions and net C footprint of this innovative system, assessed by the CAP'2ER tool over the 2017-2020 period.

Materials and methods

The OasYs dairy cattle system is experimented since June 2013 in a plain area traditionally affected by summer droughts located south of Brittany (Lusignan, Nouvelle Aquitaine, France), in an INRAE facility. The forage system (91.5 ha) produces the fodder necessary to feed the dairy cattle herd (72 milking cows, and replacement heifers) without irrigation and with limited use of mineral N fertiliser (<50 kg N/ha/year on grasslands) and of pesticides (<10% of regional references). Forage resources are diversified in terms of species, cultivars, age and management, and priority is given to their grazing (Novak *et al.*, 2018). Five- and four-year multispecies and legume-rich grasslands (52 ha) represent the heart of the forage system, complemented by annual crops (maize, grain sorghum, cereal-legume mixtures). Calving periods are centered on grassland peak productions (spring and autumn). The extension of lactation length to 16 months and the three-way crossing of dairy breeds (Holstein, Scandinavian Red, and Jersey) are used to improve reproduction performance and cow lifetime (Novak *et al.*, 2018). The CAP'2ER tool, based on Life Cycle Assessment following the IPCC methodology (https://cap2er.fr/Cap2er/), was used to determine GHG gross emissions, the C footprint of the milk, the N balance and associated indicators over the 2017-2020 period. Results were compared to national references as regional references were not available for similar systems (*i.e.* lowland systems with less than 30% maize).

Results and discussion

The N balance showed small surpluses (48 kg N ha^{-1} on average) and varied between 27 and 69 kg N ha^{-1} mainly according to the legume N fixation amounts, which represented 52 to 72 % of total N inputs (Table 1). N use efficiency at the farm scale varied between 37 and 62% and was also closely linked to the amount of legumes present each year on cropland. These results are quite good when compared to other dairy cattle systems from lowland areas of France, based on grassland or on grassland and maize (Table 1) or to other literature data (Hutchings *et al.*, 2020). These results can be explained by the smaller amounts of mineral N fertiliser and concentrates used in OasYs, resulting in high protein feed self-sufficiency (94 % on average).

Table 1: N balance and N use efficiency of OasYs compared to other French dairy systems

	OasYs				Inosys data on 2009-2013 (Foray *et al.*, 2017)	
	2017	2018	2019	2020	Grassland-based lowland systems	Grassland and maize lowland systems
Forage (kg N ha^{-1})	0	0	4	0	10	6
Concentrates (kg N ha^{-1})	9	3	7	9	37	43
Mineral N fertiliser (kg ha^{-1})	25	15	15	6	45	65
Symbiotically-fixed N (kg N ha^{-1})	47	73	74	47	18	19
TOTAL N inputs (kg N ha^{-1})	91	101	110	72	120	145
TOTAL N outputs (kg N ha^{-1})	52	44	41	45	40	49
N surplus (kg N ha^{-1})	39	57	69	27	80	96
N use efficiency (%)	57	44	37	62	33	34

GHG gross emissions expressed in kg CO_2 equivalent (CO_2e) per litre of fat and protein corrected milk (FPCM) decreased from 2017 (0.90) to 2020 (0.78). They were lower compared to other dairy cattle systems from French lowland areas (Table 2) or to many other countries (Mazzetto *et al.*, 2021). As for N surplus, these results could be explained by the sharply reduced use of mineral N fertiliser and concentrates counterbalanced by a large use of legumes, and certainly also by the new livestock breeding strategy. When the soil C storage is taken into account, the net C footprint of milk (0.78 kg CO_2e litre^{-1} FPCM in average) is higher than the average of French grassland-based systems from lowland areas (0.67) but it remains lower than other systems using more maize. OasYs is indeed based on temporary grasslands that store less C in soils than permanent ones, and the C stored in the above-ground biomass of trees is not yet taken into account by CAP'2ER.

Table 2: C footprint of OasYs compared to other French dairy systems

	OasYs				CAP'2ER data on 2013-2019 (Goumand & Castellan, 2021)	
	2017	2018	2019	2020	Grassland-based lowland systems	Grassland and maize lowland systems
Proportion of grasslands in UAA	67%	64%	64%	65%	80%	58%
FPCM (litres cow^{-1})	6624	6468	6915	6978	5507	7187
Concentrates (g litre^{-1})	42	28	54	63	130	161
GHG gross emissions (kg CO_2e litre^{-1} FPCM)	0.9	0.83	0.83	0.78	0.99	0.96
Soil C storage (kg CO_2e litre^{-1} FPCM)	0.05	0.06	0.06	0.05	0.32	0.15
GHG net emissions (kg CO_2e litre^{-1} FPCM)	0.85	0.78	0.77	0.73	0.67	0.82

UAA: utilised agricultural area; FPCM: fat and protein corrected milk; GHG: greenhouse gases

Conclusion

The innovative agroecological dairy system OasYs, based on diversified and legumes-rich forages resources and a new livestock breeding strategy, showed good results either on the N balance or on the GHG emissions per litre of FPCM. Its net C footprint could be further improved by extending the duration of grasslands, *e.g.* through relay cropping. It was yet certainly overestimated by the CAP'2ER tool, which currently does not take into account the above-ground C stored by agroforestry trees. Redesigning dairy systems by integrating coherently the forage and livestock systems through an agroecological approach seems to be a promising strategy to reduce their environmental burden.

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