European Journal of Agronomy 99 (2018) 1–12

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Production efficiency, costs and environmental impacts of conventional and dynamic forage systems for dairy farms in Italy

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ARTICLE INFO

Keywords:
Environmental impact dairy farm
Conventional forage system
Corn monocropping
Dynamic forage system
Carbon calculator

ABSTRACT

Over the last few decades, scientists, decision-makers, consumers and the more volatile marketplace impose to dairy farms to manage forage systems more sustainably, while maintaining profitability. Hence, shifting from a conventional forage system based mainly on monocropping corn (CONV_FS) to a more flexible one, defined as dynamic forage system (DYN_FS), that is based on increasing on-farm cropping of leguminous species, double cropping, scheduling of forage cuts to early stages of growth, and the adoption of silage conservation in place of haymaking, could help increasing overall system sustainability. A multi-year study, conducted on two commercial high productive dairy farms, analyzed this shift from an agronomic, economic and environmental point of view. The two farms milked 127 and 262 cows, farmed 56 and 102 ha, and had a milk production intensity of 20 and 26 t/ha per year, respectively. All the data necessary to determine dry matter (DM) yield, forage quality, in terms of crude protein (CP) and metabolizable energy (ME), the nitrogen balance, agrochemical management, the energy balance and efficiency, labor use, economic budgets, and carbon footprint of the two forage systems were on farm measured and collected. One hectare of tillable land, 1 t of DM or CP, and 1 GJ of ME were chosen as functional units. The adoption of DYN_FS increased overall system efficiency (increased DM, CP and ME yields per hectare), reduced reliance on external inputs (chemical N and pesticides), led to a more equilibrated N balance, reduced agrochemical use intensity and potential ecotoxicological impacts, increased energy use efficiency and reduced carbon footprint when compared to CONV_FS. Shifting from DYN_FS to CONV_FS had also a positive effect on the costs sustained per hectare of tillable land, whereas the labor requirements increased slightly on a per hectare basis, but decreased relative to the chosen functional units. Finally, DYN_FS provided more ME and CP than CONV_FS, but maintained a similar milk production and quality.

We have concluded that the new dynamic forage system DYN_FS has the potential of being profitable and could enhance production efficiency and environmental quality in the more intensive forage systems adopted on dairy farms in the Po plain in Italy.

1. Introduction

The intensification of dairy farming systems has been accompanied by the development of corn silage and intensively fertilized grasses throughout Europe, while the protein supplementation of dairy rations has been left to purchased soybean meal, which is predominantly produced overseas (Borreani et al., 2013; Lehuger et al., 2009). In the same way as other European countries, the Italian dairy sector has also been affected by an intensification process, as a result of an increase in the number of dairy cows per hectare of land, the acquisition of genetically improved dairy cattle, and an increase in concentrates in the diet (Alvarez et al., 2008; Bava et al., 2014), and this has resulted in significant effects on the efficiency, and thus on the economic results of the farms.

Italy produces about 11.5 million tonnes of milk a year, which represent about 7.5% of the milk produced in the EU-28 (CLAL, 2016). Around 80% of Italian milk comes from the intensive farming systems in the Po Plain, where the high producing Italian Holstein breed is reared (Bava et al., 2014; Borreani et al., 2013). There is currently a lack of arable land in the Po plain and land charges/rents are high. Over the years, the climate and the high soil fertility of the area have favored the cultivation of crops that are thought to produce a high dry matter

Abbreviations: EUE, energy utilization efficiency; FCM, fat corrected milk; CONV_FS, conventional forage systems; DYN_FS, dynamic forage system; ME, metabolizable energy; CP, crude protein

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https://doi.org/10.1016/j.eja.2018.06.004
Received 23 January 2018; Received in revised form 5 June 2018; Accepted 7 June 2018
1161-0301/

(DM) yield per hectare and to be more suitable for an easy conservation by ensiling (Borreani et al., 2013). Corn for silage is the most frequently cultivated crop, to the detriment of forage legume crops and other annual grasses, which are considered to be low producing crops that are difficult to ensile (Borreani et al., 2013; Peyraud et al., 2009). As a consequence, most of the dairy farms operating in the Po plain have abandoned annual forage grasses and legumes and have specialized in corn silage production, with the aim of being self-sufficient for their animal feeding energy requirements, although they buy most of the protein sources. These changes have been favored to a great extent by an era of low-cost soybean meal on the market (Wolf, 2010) and of cheap non-renewable energy, which has encouraged high fertilizer and pesticide inputs (Peyraud et al., 2014). Hence, the dairy forage systems of the Po plain are currently extremely simplified, with corn crops being grown on up to 90% of the utilized agricultural area. Such a system relies on a high external input and non-renewable energy consumption, with an increasing demand for nitrogen fertilizers and agrochemicals to maintain the high DM yield of mono-cropped corn, and concerns have thus arisen about the environmental impact of intensive forage systems on dairy farms, the traceability of supply chains and about food security (Lehuger et al., 2009). Furthermore, the volatility of the market prices of corn and soybean that has resulted in an increased uncertainty about concentrate costs makes the corn-silage based cropping system no longer economically, other than environmentally, sustainable for dairy farms (Wolf, 2012).

Therefore, in order to maintain farm competitiveness, to decrease feeding costs and to increase farm protein self sufficiency (Peyraud et al., 2014; Wolf, 2012), producers need to develop more sustainable cropping systems by considering crop sequencing to take advantage of the inherent internal resources (synergisms, nutrient cycling and soil water) while also capitalizing on external resources, such as the weather, neighboring farm interrelationships, markets, government programs and new technologies (Liebman et al., 2008; Tanaka et al., 2007). Tanaka et al. (2002) developed the concept of *dynamic cropping systems* and defined them as a long-term strategy of annual crop sequencing that optimizes crop and soil use options, while attaining production, economic and resource conservation goals by using sound ecological management principles.

From our perspective, this means growing more crops (both annual and perennial) in the forage system and re-designing crop rotations and intercropping in such a way as to develop a more self-sufficient, integrated and closed-loop livestock and vegetal production system, using an agro-ecological and ethological approach with the final objective of achieving an eco-functional intensification of sustainable livestock production (Guyader et al., 2016; Tilman et al., 2002). Forage production systems that serve dairy farms should be modified to attain an increased protein self-sufficiency in order to partially or totally replace soybean and other protein concentrate imports and to increase the amount of crops that are not suitable as food and fiber for humans but utilizable by livestock. Because of its high starch content, corn silage is a good source of ruminally fermentable carbohydrates, but it is low in protein (Brito and Broderick, 2006). A new forage system, which has hereafter been defined as *dynamic forage system*, should be based on the setting up of a crop sequence and diversification that are able to satisfy the requirements of high producing dairy cows, by providing forages and feeds with high concentrations of protein and energy, through early cutting strategies associated with efficient forage conservation techniques, and at the same time reducing external inputs, economic costs and environmental impacts (Tabacco et al., 2016). This crop sequence is dynamic, in relation to the market prices of the driving commodities for protein (soybean meal) and energy (corn grain) supply for dairy rations. In particular, it integrates the potential production of starch by corn, with other forages (grasses and legumes) that could have high nutritive and feeding value for dairy cows if produced at an early stage of growth (Borreani et al., 2007; Valente et al., 2000; Zebeli et al., 2010) and preserved by ensiling (Colombari et al., 2001).

Compared to corn silage, conserved Italian ryegrass, alfalfa and grass-legume mixtures are complete feeds, which are rich in energy, protein and minerals (Brito and Broderick, 2006; Peeters, 2008; Valente et al., 2000) and, if harvested at a young maturity stage, may be used to support a reasonable milk production, even without supplements (Randby et al., 2012; Steinshamn and Thuen, 2008). Furthermore, alfalfa, Italian ryegrass and corn are also complementary for agronomic reasons. Italian ryegrass, planted in late summer or early autumn, grows over winter, thus contributing to the soil covering (i.e. reducing soil erosion and nitrate leaching), and it could provide supplemental high quality forage if it is harvested in early spring before establishment of the subsequent corn crop. Alfalfa can be successfully used in a crop rotation with corn, as it supplies nitrogen to agro-ecosystems via its unique ability to fix atmospheric N_2 (Russelle et al., 2001), increases soil organic matter (Peoples et al., 1995) and offers the possibility of differing harvest schedules, thus contributing to reducing labor and equipment constraints (Brito and Broderick, 2006), as well as stimulating the productivity of the subsequent crops. Diversifying cropping systems and including forages in rotation with annual crops can help to reduce yield losses from insects and diseases (Altieri, 1999), to reduce weed community density and to minimize the need for herbicides (Anderson, 2005; Liebman and Dyck, 1993), thus contributing to the improved resilience of cropping systems. Furthermore, economic and environmental benefits are enhanced when crop rotations with forages are set up in forage systems to serve livestock enterprises, especially dairy farms (Russelle et al., 2007).

Over the last few decades, several studies have been conducted to evaluate environmental impacts and agronomic efficiency improvements with the aim of showing the cumulative effects of crop management strategies on crop yields, profitability, weed competition and soil properties (Alluvione et al., 2011; Coulter et al., 2011; Davis et al., 2012; Deike et al., 2008). However, most of these studies were conducted under controlled conditions on confined experimental plots of limited dimensions, focusing on one or a few aspects of crop management. This approach could lead to divergent results and limited suggestions, and points out the need for a better understanding, directly on farm, of the performance of different cropping systems. On-farm research, under conditions that are representative of those encountered by producers, that consider to make the transition from standard production practices to new dynamic forage systems are therefore needed to help them make right input and practice changes (Greene and Kremen, 2003; Karlen et al., 2007). The development of farmer-researcher partnerships and system approaches will improve our understanding of the complex interactions that take place between farming systems and the environment (Karlen et al., 1995), and could give us a more complete vision of the processes involved in the management of a cropping system that needs to produce feedstuffs for lactating cows (Long and Ketterings, 2016).

In consideration of all aforementioned aspects, we conducted a multiyear on-farm study on two commercial dairy farms with the aim of testing the hypothesis that dynamic forage systems can provide yields (in terms of DM, CP and ME) that match or exceed those obtained from the mono-cropped corn silage systems that are conventionally adopted in NW Italy, while reducing the environmental impact of the production system and the cost of the produced feedstuffs. We focused on evaluating how such an alternative cropping system, coupled with highly efficient forage conservation practices, affect the nitrogen, energy, labor and economic budgets as well as the carbon footprint of dairy forage systems, compared with the crop management systems conventionally adopted in most of the dairy farms operating in the Po plain in Italy.