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Maize grain and silage yield and yield stability in a long-term cropping system experiment in Northern Italy

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ABSTRACT

This study assesses maize yield and yield stability over a 26-year period in several cropping systems that are part of a long-term crop rotation and agronomic input experiment established in 1985 in Lodi, Lowland of Lombardy, Po Valley, Northern Italy. This experiment compares five fodder crop rotations, specifically: (i) an annually repeated double crop (R1) of autumn-sown Italian ryegrass + spring-sown maize, both used for silage; (ii) a three-year rotation (R3): grain maize (first year) – autumn-sown barley (*Hordeum vulgare* L.) + spring-sown maize, both for silage (second year) – Italian ryegrass + maize, both for silage (third year); (iii) a six-year rotation (R6): Italian ryegrass + silage maize, both for silage (years 1, 2 and 3 of rotation) – a mixed meadow of white clover (*Trifolium repens* L.) and tall fescue (*Festuca arundinacea* Schreb) for hay making (years 4, 5 and 6 of rotation); (iv) a continuous grain maize (CM); and (v) a permanent meadow, established at the beginning of the experiment. All phases of the rotations were carried out every year. Each crop rotation received two levels of agronomic inputs consisting in synthetic and manure fertilization and herbicide rate, corresponding to high (A) and low (B). Treatment A represented a snapshot of agronomic inputs (synthetic fertilizers N–P–K, manure and herbicide amounts) normally applied by the farmers in the region in 1985, when the experiment was undertaken, while treatment B consisted in a 30% reduction of synthetic and manure fertilizers and a 25% reduction of herbicide rate compared to treatment A. The primary objective of this study was to evaluate the long-term effects of crop rotations and the reduction of inputs on maize yield and yield variability. The following conclusions can be drawn: firstly, over 26 years, the yield of grain maize in rotation increased steadily whilst the yield of continuous maize decreased slightly; secondly, a 30% reduction of agronomic inputs decreased the average yield less than proportionally for both grain and silage maize; thirdly, within a given crop rotation, grain and silage maize yields are more stable with higher inputs; and finally, yield stability of grain and silage maize increases with longer rotations. Therefore, management options oriented at increasing cropping system biodiversity have important implications on reducing the temporal variability on maize yield.

1. Introduction

Maize (*Zea mays* L.) is the primary crop in the plain of Northern Italy, a region characterized by intensive cropping and dairy farming activities (Zavattaro et al., 2012). In the Lowland of Lombardy, where the crop is fully irrigated and generously fertilized, yield normally ranges between 10 and 14 Mg DM ha^{-1} for grain and 16–26 Mg DM ha^{-1} for silage maize (Onofrii et al., 1993). Maize is also a key crop for manure utilization. In fact, in order to maximize the amount of feed energy produced per unit area, and to reduce forage and manure transportation, farmers tend to cultivate silage maize in the areas surrounding the dairy cattle sheds. Grain maize is also widely cultivated for animal feeding, and maize stover is predominantly used as a composting substrate for livestock manure in the area of the study. Yet, silage maize is a suitable substrate for biogas production, and it is increasingly used, in combination with cattle manure, as a feedstock for biogas plants to produce methane via anaerobic digestion (Amon et al., 2007). Nevertheless, maize cultivation exerts a negative influence on the environment, owing

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Table 1
List and sequence of crops and crop rotations compared in the experiment. IR + SM: Italian ryegrass + maize (both for silage); RM: rotational meadow; GM: grain maize; B + SM: barley + maize (both for silage).

Year of rotation	Annual rotation (R1)	Three-year rotation (R3)	Six-year rotation (R6)	Continuous grain maize monocrop (CM)	Permanent meadow (PM)
1	IR + SM	GM	IR + SM	GM	PM
2		B + SM	IR + SM		
3		IR + SM	IR + SM		
4			RM		
5			RM		
6			RM		

to: (i) high nitrate losses compared to perennial grass (Randall and Goss, 2001); (ii) high fossil energy required for agronomic inputs (Pimentel and Patzek, 2005); and (iii) high nitrous oxide emission to the atmosphere (Crutzen et al., 2008). Therefore, it is necessary to identify alternative cropping systems that represent a compromise between the need to maintain high yield and yield stability and the need to mitigate the environmental side effects of maize cultivation. The objective of these cropping systems is to diminish the reliance on external inputs while improving the economic and environmental sustainability of the farming system (Robertson and Swinton, 2005). In particular, the reduction of year-to-year variability has the potential to decrease the risk associated with the farming enterprise (Smith et al., 2007).

The overall trends and the cumulative impacts of crop rotations and management systems are best studied through long-term experiments (Aref and Wander, 1998; Mitchell et al., 1991). In fact, research focused on single crops and based on annual experiments may obscure relevant aspects of the behavior of the cropping systems, because it only allows the evaluation of the systems in a transient state. Conversely, multi-year and multi-crop experiments are valuable sources of information because they provide data in which the unknown effects of previous treatments are minimized (Acock and Acock, 1991; Johnston, 1997; Mitchell et al., 1991). Moreover, evaluating year-to-year variability in crop yield is important because simulation studies indicate that fluctuations in productivity tend to increase with climate change (Dai et al., 2001). Therefore, both yield and yield stability should be evaluated in long-term field experiments (Swift, 1994). Interpretation of year by treatment interaction by conventional analysis of variance is difficult because of the complexity of factors determining the crop environment and yield variability (Raun et al., 1993). Regression stability analysis is an effective technique for understanding year × cropping system interactions (Piepho, 1998; Raun et al., 1993). In particular, it allows a transparent, straightforward evaluation of the performance of the treatments in contrasting situations of low-yielding and high-yielding years (Grover et al., 2009). The basic assumption for stability analysis is that it is possible to compare treatment response to good and poor environments regardless of the reasons why these environments are good or bad (Raun et al., 1993). A stable system is by definition the one that changes least in response to environmental variation (Lightfoot et al., 1987).

A long-term cropping systems experiment, comparing rotations that are intended to provide dairy cattle feed and to receive farmyard manure application, was established in 1985 in Lodi (Lombardy, Northern Italy) and is still ongoing. This experiment was designed to study not only the effects of crop rotation but also two levels of agronomic inputs. This study focuses on the evolution over time of grain and silage maize yield. Our objective was to evaluate the long-term effects of crop rotations and agronomic inputs on grain and silage maize yield and yield stability. Rotations and agronomic inputs compared in this study are widely applied by the farmers in the region.

2. Materials and methods

2.1. Site characterization and agronomic details

Details of the methodology were presented by Tomasoni et al. (2003) who reported key findings of the influence of fodder crop rotations on the weed flora. In brief, the experimental site is located in Lodi, Po Valley, Northern Italy (45°19′ N, 9°30′ E, 81 m.a.s.l.). The soil of the site is sandy-loam, classified as mollic Hapludalf. The major characteristics of the soil in the arable layer (0–0.3 m) at the outset of the experiment (year 1985) were: clay (<0.002 mm) 9.9%; silt (0.05–0.002 mm) 24.7%; sand (2–0.05 mm) 65.4%; organic matter 0.15 (g kg^{-1}); available soil water 9.76 (m m^{-3}); bulk density 1.58 Mg m^{-3}; pH (H_2O) 6.5; C.E.C. 11.3 (cmol$_{(+)}$ kg^{-1}).

The climate is sub-continental, with an average annual rainfall of about 800 mm, relatively well distributed around the year, and an average annual mean daily temperature of 12.5 °C, January being the coldest month (1.1 °C) and July the hottest (22.9 °C) (Borrelli and Tomasoni, 2005).

The field experiment was undertaken in 1985 and it is still ongoing. The experiment compares ten cropping systems, deriving from the combination of five crop rotations and two agronomic input levels. The experiment was a randomized, complete block design with a split plot arranged in two agronomic input levels as main plots, five rotations as subplots, and three replicates.

The compared crop rotations were: (i) an annually repeated double crop (R1) of autumn-sown Italian ryegrass (*Lolium multiflorum* Lam.) + spring-sown maize, both for silage; (ii) a three year rotation (R3): grain maize (first year) – autumn-sown barley (*Hordeum vulgare* L.) + spring-sown maize, both for silage (second year) – Italian ryegrass + maize, both for silage (third year); (iii) a six year rotation (R6): Italian ryegrass + maize, both for silage (years 1, 2 and 3 of rotation) – a mixed meadow of white clover (*Trifolium repens* L.) and tall fescue (*Festuca arundinacea* Schreb) for hay making (years 4, 5 and 6 of rotation); (iv) a continuous grain maize monocropping (CM); (v) a permanent meadow (PM), sown at the outset of the experiment with ladino white clover and tall fescue, and subsequently colonized by natural vegetation (grasses, legumes and forbs) (Table 1). All phases of the rotations were carried out every year. Because this study focuses on maize yield and yield stability, have been taken into account only the rotations in which maize is present.

Each crop rotation has been treated with two levels of agronomic inputs: (i) input A represents the ordinary crop management adopted by the farmers in the region when the experiment initiated (year 1985); (ii) input B received about 70% of the amount of synthetic and manure fertilization and 75% of herbicide rate of application compared to treatment A. Silage maize is present in crop rotations R1, R3 and R6, while grain maize is present in cropping system CM and R3. Weeds were controlled chemically on maize, both for silage and grain, in all crop rotations, using the herbicide metolachlor + terbuthylazine-based product, applied at the pre-emergence stage (spring) on maize crop at the rate of