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# Options to reduce N loss from maize in intensive cropping systems in Northern Italy

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ABSTRACT

Maize (*Zea mays*, L.) is not only the main crop in the intensively cultivated Po Plain (Northern Italy), but also the one that produces the largest N Surplus. This study is based on experimental data from the Tetto Frati long-term trial (Turin, NW Italy) to demonstrate that the impact on soil and water quality of high-yielding, maize-based cropping systems can be reduced through proper management.

Nitrogen use efficiency and loss indicators were calculated and compared among various management options: (i) maize monoculture at high N fertilizer rates for grain production (most widespread management), (ii) entire plant (with straw) harvest, (iii) double-cropping system with a winter crop, (iv) maize–grass ley rotation, and (v) change in fertilizer type.

The entire maize plant removal reduced N leaching by 10–20%; however, carbon sequestration was also reduced. A maize–Italian ryegrass double cropping system improved the efficiency of organic fertilizers, and reduced leaching by 25–40% relative to monoculture. A rotation with grass ley reduced N impact only when fertilized with urea, and not when organic fertilizers were used. Urea, slurry, and farmyard manure were equally utilized by the crop; if distributed and incorporated just before sowing, both organic fertilizers built up the soil organic matter content and reduced N leaching by 20–50% with respect to urea. This study has shown that farmers in NW Italy have several opportunities to continue cultivate maize thus accomplishing agri-environmental legislation.

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## 1. Introduction

Maize (*Zea mays*, L.) is one of the most diffuse crops throughout the world (Leff et al., 2004), as it adapts to very different climatic and management conditions (e.g. Chang and Janzen, 1993; Chikowo et al., 2004; Kristiansen et al., 2005; Schröder et al., 2005; Zhen et al., 2006; Payet et al., 2009). It is also one of the most versatile of crops—whether as a grain or whole crop. Maize grain is used for both human and animal consumption as well as for industrial or energy purposes. The whole plant can serve as forage or biomass for biogas production or its straw can be chopped and incorporated into the soil, or harvested to function as livestock bedding.

Maize has endured a number of criticisms. Frequently accused of being a crop that wastes water because it is usually irrigated, it actually has been shown to convert water to biomass more efficiently than many alternative crops (see Katerji et al., 2008 for a literature review of water use efficiency coefficients, and Grignani et al., 2009 for an analysis of crop irrigation requirements in Northern Italy). Similarly, maize was often tagged as the crop that puts environmental quality at a greater risk than others, following Pimentel's work (1996) and the long series of trials that focused on the environmental and economic effects of agricultural practices associated with high N losses (Kramer et al., 2002). In fact, in a warm and water-available climate, maize is a most efficient user of these inputs. Since only rarely is a productivity decrease due to excess resources, farmers allocate most of their fertilizer, irrigation water, and energy resources to maize.

Maize is the main crop in the fertile Po Plain (Northern Italy), which is the largest and most intensive agricultural area in Italy, as it hosts 36% of the Utilized Agricultural Area (UAA) and 75% of the livestock (ISTAT, 2000). Maize is cultivated on as much as 23% of the UAA for grain production (ISTAT, 2000; Autorità di Bacino del Fiume Po, 2006). In the Northern Italy climate, the plant reaches physiological maturity at the end of summer; thereafter, the grain continues the drying process. Since it never attains a humidity level that is needed for conservation, it requires drying post-harvest by an external heat source. Its straw is normally chopped and incorporated into the soil or harvested to serve as livestock bedding. Alternatively, the entire maize plant is frequently harvested prior to its physiological maturity, chopped, and then ensiled as ruminant forage. Other uses of maize are not common in Northern Italy. Local regulations (e.g. Regione Piemonte, 2009) promote the use of

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winter catch crops as maize leaves the soil bare during winter. The most diffuse winter cover used in the region is, in fact, a secondary crop of Italian ryegrass (*Lolium multiflorum*, Lam.) that is harvested in May when maize is late-sown.

The large amounts of slurry or farmyard manure that are produced across the territory make organic fertilizers largely available to any crop, but especially to maize, which is the typical crop of pig, beef, and dairy farms. According to common practice, N fertilizer is partly distributed in spring just before sowing in the form of slurry or manure, and partly top-dressed at ridging as mineral fertilizer (Bassanino et al., 2007, 2011). This management complies with local implementations (D.M. 7 April 2006) of the Nitrates Directive (Anonymous, 1991) and the Water Framework Directive (Anonymous, 2000). No singular agreement exists on how best to reduce the use of N sources across Europe; therefore, every country or region (as in Italy) has its own legislation. The logic behind this choice is that European Union-wide objectives, such as those to protect water resources, can be optimized best through area-specific efforts.

Scientific data may help identify management solutions that can be accepted by farmers and meet environmental targets. A deep knowledge of the possibilities, constraints, and practices of local farms is essential in order to propose viable alternative practices (Grignani and Zavattaro, 2000; Zhen et al., 2006; Ju et al., 2007; Bassanino et al., 2011). Although comparisons of single agronomic factors or of management packages can be found in the literature (e.g. Borin et al., 1997; Grignani and Zavattaro, 2000; Grignani and Laidlaw, 2002; Sacco et al., 2003a; Morari et al., 2012; Perego et al., 2012), few experimental trials have been designed to evaluate the sustainability of a range of management options spanning medium and long term experiments (Nel et al., 1996; Yamoah et al., 1998; Denison et al., 2004).

This paper considers how to reduce the N impact of intensively cultivated maize in the Western Po Plain. Our aim is to evaluate the following fertilization management options available to the region's local livestock farmers: (i) total plant harvest, (iii) double cropping system with a winter catch crop, (iii) grass ley rotation with the maize, and (iv) fertilizer type change. All tested cropping systems are viable options for local livestock farms. We test the hypothesis that maize, if well managed, may exert a limited environmental impact on the soil and water quality, maintain high yields, and efficiently recycle large amounts of manures, utilizing data from the long-term platform of Tetto Frati of the University of Turin. Only nitrogen is considered; other nutrients and water issues are outside the scope of this evaluation. Same site and related studies can be found by Borda et al. (2011) who evaluated phosphorous and Bertora et al. (2009a) who first presented a greenhouse gas emission analysis.

## 2. Materials and methods

We report and discuss data from the long-term platform of Tetto Frati at the Experimental Centre of the University of Turin during 1993–2006. Grignani et al. (2007) and Bertora et al. (2009b) have previously described the soil, site, and treatments; relevant points of those reports will be presented hereafter.

The trial site lies on deep, coarse, calcareous, free-draining soil (see also Lo Russo et al., 2003). The texture is loam. The initial soil N content was 1.14 mg kg$^{-1}$ with a C:N ratio of 8.6. Its temperate, sub-continental climate is characterized by two main rainy periods that occur during spring (April and May) and autumn (September–November). Total average annual precipitation is 750 mm. Since 1992, the experiment (a randomized block design with three replicates) has compared, at plot scale, 38 different combinations of maize-based cropping systems and fertilization managements. To ensure representative results, typical farm machines and agronomic techniques were adopted.

Our analysis considered the following cropping systems: (i) maize for grain production (Mg); (ii) maize for silage (Ms); (iii) double annual crop rotation with Italian ryegrass in autumn and winter, and maize for silage in spring and summer (Mr); and (iv) grass ley rotation with maize for silage (Ml) in which the first ley phase spanned 1992–1994 and the second ley phase spanned 1998–2001, for a total of six years in the monitored period. These cropping systems were then overlaid with several fertilization managements: (i) urea at four levels (U100, U200, U300, and U400), (ii) bovine slurry (S) at two levels (Low and High), (iii) composted farmyard manure (F) at two levels (Low and High), plus a control (0N). Across the experimental duration, supplied organic fertilizer amounts were kept constant while N varied according to the varied nutrient concentration associated with manures.

Table 1 reports the average amount of total-N supplied to each cropping system. For slurry and manure, the average dry matter content was 5.7 and 25.7%, respectively. Maize mineral and organic fertilizer mechanics included distribution to the soil surface and incorporated within one day; sowing followed soon after. All fertilized treatments were top-dressed with a fixed amount of 100 kg ha$^{-1}$ of urea-N, distributed and incorporated by ridging at the maize jointing stage. For leys, fertilizers were distributed to the soil surface during March at growth resumption and during May after the first cut. To eliminate any phosphorous (P) or potassium (K) direct or interactive effect on N results, P and K were over-supplemented with simple mineral products (superphosphate and potassium chloride).

### 2.1. Crop management

Both grain and silage maize underwent the same crop management and used the same hybrid. Sowing occurred during mid-April to mid-May in the Ms, Mg, and Ml systems, and in late May in the Mr system (after the Italian ryegrass harvest and tilling with a spading machine). Maize was treated with chemical weed control and sprinkle irrigation in which the N content was measured as negligible (less than 3 mg l$^{-1}$ of N). Silage maize was harvested in early September (physiological maturity) while grain maize was harvested from late September to early October. The maize residues in the Mg treatments were chopped in November or December and then incorporated into the soil with a rotavator.

Italian ryegrass (*L. multiflorum*, Lam.) was sown in the Mr system soon after the silage maize harvest (early October). Its seedbed was prepared using a rotavator. The crop was harvested during mid- to late May, the grass sods were destroyed using a spading machine and a rotavator, and maize was then sown.

Cocksfoot grass (*Dactylis glomerata*, L.) was used in the first ley cycle and tall fescue (*Festuca arundinacea*, Schreb.) in the second cycle. White clover (*Trifolium repens*, L.) naturally developed in the control plots but was absent in those fertilized. The sward was sown in September (1992 and 1997) after basic fertilization and soil tillage by spading machine, rotavator, and disk harrow. Three or four cuts were performed each year during the heading stage. Ley irrigation was like that done for maize, and a spading machine and rotavator destroyed the grass sods in autumn 1994 and 2001.

### 2.2. Measurements

The N supplied to the plots was calculated from the amount of fertilizer distributed and the nutrient concentration of the fertilizer. We assessed the aboveground crop biomass production by sampling an 18 m$^2$ area for maize, and 10 m$^2$ for both Italian ryegrass and leys; its production was expressed as oven-dried matter (DM). In the case of crop nutrient uptake, it was determined from

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