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Effects of N sources and management strategies on crop growth, yield and potential N leaching in processing tomato

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ABSTRACT

A 2-year field experiment was carried out in Central Italy on processing tomato (*Lycopersicon esculentum* Mill., cv PS1296). The aim was to assess the effects of various N sources and methods of distribution on crop growth and yield, as well as on the potential risks of nitrate leaching. Processing tomato was fertilized by using (i) green manuring with several cover crops (vetch and barley alone and in several mixtures), (ii) broadcast organic fertilizers (poultry manure and by-product of leather factory), (iii) fertigation with organic fertilizer (by-product of leather factory) and (iv) fertigation with a mineral N fertilizer. N accumulation and C/N ratio were measured in the cover crops at killing date. Tomato growth and N accumulation were determined fortnightly. The concentration of NO_3-N in the soil solution was measured by a suction lysimeter at 0.9 m N supply from pure barley or from mixtures with high proportion of barley (i.e. 50% or higher) were inadequate for tomato growth. Pure vetch ensured an optimal N status to the succeeding crop, but led to nitrate leaching. The mixture vetch 75% + barley 25% ensured an adequate amount of N for tomato, while reducing the NO_3-N concentration in soil solution. Poultry manure and by-product of leather factory at low N rate (i.e. 100 kg N ha^{-1}) were both inadequate to fulfil tomato requirements. At the same N rate, fertigation with the organic fertilizers gave the same good efficacy of fertigation with the mineral fertilizer, ensuring higher environmental sustainability. The integrated use of fall-winter cover crops and fertigation could represent a sound strategy for conservative horticulture.

1. Introduction

In the last decades, the sustainable use of nitrogen (N) fertilizers in agriculture has become one of the main concerns all over the world for researchers, producers and policy-makers (Bindraban et al., 2015; Cameira and Mota, 2017; Grizzetti et al., 2011). This is particularly crucial for vegetable crops, such as processing tomato which requires high nitrogen and water supply (Camargo and Alonso, 2006; Ronga et al., 2017; Tei et al., 2015) and it represents one of the most important vegetables in the world, in the Mediterranean area and in Italy (35 Mt, 16 Mt and 5.2 Mt, respectively) (WPTC, last update 15/09/2017).

The possibility of making a sustainable use of N-fertilizers has been commonly related to the ability of meeting the specific crop requirements throughout the growing season. In this respect, key factors are the selection of N-rates (Tei et al., 2003, 2002) and timing of application (Hansen et al., 2000; Farneselli et al., 2015). For both aspects, an increase of fertilization efficiency can be achieved by considering the actual crop status in a given moment, for example by using the results of quick field tests (Farneselli et al., 2014, 2006; Padilla et al., 2014; Peña-Fleitas et al., 2015; Thompson et al., 2017).

Apart from N rate and application timing, N source and application method are also fundamental (Benincasa et al., 2011; Tei et al., 2015). The broadcast application of mineral N fertilizers has been, so far, the most widespread technique. However, this may lead to consistent losses through various hydrological and gaseous pathways (Simonne et al., 2017; Solaimalai et al., 2005). Furthermore, the apparent recovery is low whenever N is broadcast distributed to the field (Benincasa et al., 2017; Greenwood et al., 1989). Clearly, an improved sustainability of N-fertilization should be pursued by the adoption of alternative N sources (Raviv 2009; Sambo and Nicoletto, 2017), together with innovative application techniques. These latter aspects have been less considered in literature, with respect to application rate and timing.

In this paper, we took into consideration some potentially important N sources, such as green manuring, poultry manure and by-products of leather factories. Green manuring is increasingly recognized as a good practice for sustainable production in processing tomato, based on the

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use of appropriately selected cover crops (Schipanski et al., 2014; Tonitto et al., 2006; Tosti et al., 2012; Tribouillois et al., 2016). In particular, grass–legume bicultures have been extensively studied for their potential to both capture residual soil N and supply N to the subsequent crop (Finney et al., 2016; Lawson et al., 2015; Tosti et al., 2014). However, the actual availability of N that is left to the following crop is rather difficult to predict, as it depends on a number of factors, such as species, C/N ratio, pedo-climatic conditions, plant densities and cultivation technique. Literature references show that N release from green manure biomass and N demand of the cash crop may not match, either in time or in space. Indeed, in widely spaced vegetables, such as processing tomato, broadcast incorporation of green manure may be inadequate especially in the early growth stages when roots are not able to uptake N far from the row (Bath, 2001).

The use of poultry litter has also been a common practice in organic cropping systems with several crops in several countries (Amanullah et al., 2010; Ewulo et al., 2008; Ghorbani et al., 2008). This organic fertilizer may promote biological activities in the soil, while enhancing nutrient availability to the crop and increasing plant disease suppressiveness (Mehdizadeh et al., 2013). Likewise, the use of various types of waste as organic fertilizers has been encouraged in the last years (Agele et al., 2011; Mehdizadeh et al., 2013). Among these, the leather by-product stands out (Nogueira et al., 2011). Indeed, the leather industry produces large amounts of by-products, with high contents in chromium. After the removal of this element, a solid collagenic material with high N content is obtained, which can be used as an organic fertilizer (Kanagaraj et al., 2006; Nogueira et al., 2009). All organic fertilizers, in contrast to mineral fertilizers, may give problems because nutrient release may be slow and often difficult to predict, depending on soil and weather conditions, as well as on the composition of organic matter (De Neve, 2017).

Apart from the type of fertilizer, the amount of N recovered by a crop may also be affected by the method of application, both for organic and mineral fertilizers. In this paper, we considered fertigation techniques, which may strongly increase nutrient use efficiency. Indeed, fertigation help to achieve a better matching between N availability and crop requirements and decreases the distance between nitrogen source and the root system (Farneselli et al., 2015; Simonne et al., 2017; Solaimalai et al., 2005).

Indeed, several alternative N sources and methods of application exist, which should potentially lead to increased sustainability of N fertilization in processing tomato. Therefore, we considered processing tomato grown under a Mediterranean environment and compared various N sources (mineral or organic N-fertilizers and green manuring with winter legume and non-legume cover crops) and methods of distribution (broadcast or fertigation). Our objective was to assess their effects on crop growth, crop yield and potential nitrate leaching risks. This is relevant, because we can provide a reliable comparison of several innovative and traditional techniques altogether in the same environment, which is rarely found in literature and may provide support for technical decision systems and dynamic modelling in general.

2. Materials and methods

2.1. Experimental site, treatments and crop management

Two field experiments were carried out in 2007–2008 and 2008–2009 at the Experimental Station of the Department of Agricultural, Food and Environmental Sciences of the University of Perugia, Central Italy (Papiano, 43° N, 165 m a.s.l.). The soil was clay-loam (*Fluventic Haplustept,* Soil Taxonomy) in the top 0.5 m, with 44% silt, 36% clay, 20% sand, 1.5% organic matter (TOC = 9.1 g kg^{-1} and total N = 0.83 g kg^{-1}), high contents of extractable P (28.5 mg kg^{-1}, Olsen method) and exchangeable K (256 mg kg^{-1}), and pH_{H2O} = 7.8. At 0.5 −0.9 m depth the soil had TOC 6.8 g kg^{-1}, total N 0.9 g kg^{-1} and extractable P 6.7 mg kg^{-1} (Olsen method).

Table 1
Details of the experiment: treatment codes, N sources, methods of distribution, fertilizer-N rates.

Code	N source	Method of distribution	N rate (kg ha^{-1})
V100	Green manuring	–	–
V75B25	Green manuring	–	–
V50B50	Green manuring	–	–
V25B75	Green manuring	–	–
B100	Green manuring	–	–
$O_{poultry}$	poultry manure	broadcast	100
$O_{leather}$	by-product of leather factory	broadcast	100
F_{org}N100	by-product of leather factory	fertigation	100
F_{org}N200	by-product of leather factory	fertigation	200
F_{min}N100	mineral fertilizer	fertigation	100
F_{min}N200	mineral fertilizer	fertigation	200
N0	–	–	–
$N0_{barley}$	–	–	–

Processing tomato was grown by using different N sources, rates and methods of application: green manuring with winter legume/non-legume cover crops, broadcast organic fertilizers, organic fertigation and mineral fertigation (Table 1). Two species were used as cover crops: i.e. hairy vetch (*Vicia villosa* Roth., cultivar Capello) and barley (*Hordeum vulgare* L., cultivar Amillis). These species were sown as pure stands at the ordinary sowing rates (200 seeds of vetch m^{-2}, V100; 400 seeds of barley m^{-2}, B100) and as vetch + barley mixtures. The following mixture ratios (vetch/barley, in percentage of the ordinary sowing rates): 75/25 (V75B25), 50/50 (V50B50) and 25/75 (V25B75). For these five treatments, cover crops were incorporated into the soil, prior to tomato transplanting (see later). Two organic fertilizers were broadcast applied at crop transplanting, both at the rate of 100 kg N ha^{-1}, i.e. poultry manure ($O_{poultry}$, N_{org} = 4%; C/N = 10.2, italpollina, Italpollina spa) and by-product of leather factory ($O_{leather}$, N_{org} = 5%, C/N = 5.4, bioilsa basic, ILSA spa). Both compounds are allowed as fertilizers and soil conditioners in organic farming [Commission Regulation (EC) No. 889/2008]. As fertigation treatments, an organic liquid fertilizer (N_{org} = 8%; C/N = 2.8, by-product of leather factory, ilsadrip extra, ILSA spa) and a mineral liquid fertilizer (7.5% NO_3-N + 7.5%NH_4-N + 15% urea, radicon N30, Green Has Italia, spa) were applied at the rate of 100 and 200 kg N ha^{-1}, making up a total of four fertigation treatments (F_{org}N100, F_{org}N200, F_{min}N100 and F_{min}N200). The selection of the above two N rates was based on previous experiments in the same location using the same processing tomato cultivar (Farneselli et al., 2015; Tei et al., 2002). In all fertigation treatments, N was applied in 10 splits (2 times/week for 5 weeks) according to the expected N uptake rate for processing tomato throughout the growing season (Tei et al., 2015). Prior to all broadcast and fertigated treatments (i.e. $O_{poultry}$, $O_{leather}$, F_{org}N100, F_{org}N200, F_{min}N100 and F_{min}N200), a cover crop of barley was grown as in B100, but the above ground biomass was removed just before transplanting, so that the pre-emptive competition effect occurred in those treatments. Two unfertilized treatments were also added to the experiment as controls. In the first control (NO_{barley}), pure barley was grown as in B100, but the aboveground biomass was removed as in broadcast and fertigation treatments. In the second control (N0), no cover crop was used prior to tomato. The experimental design was a randomized block with 3 replicates and the plot size was 75 m^2 in both years. The preceding crop was always maize (*Zea mays* L. cultivar Arzano, FAO class 400) and 150 kg ha^{-1} of P205 and K20 were broadcast at ploughing, before the cover crop sowing.

The cover crops were sown on 05.11.2007 and 27.10.2008 in single rows 0.15 m apart. Barley and vetch in the mixtures were sown in the