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Alternative strategies for nitrogen fertilization of overwinter processing spinach (*Spinacia oleracea* L.) in Southern Italy

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ABSTRACT

To identify the best practice for nitrogen (N) fertilization of overwinter processing spinach, two field experiments were carried out in the Foggia plain (Southern Italy), one of the most vocated area for leafy vegetables production. The field trials were aimed to define and suggest the proper fertilizer dose, typology and the right time of application. Experiment 1 evaluated four N fertilizer doses (0, 150, 225, 300 kg ha^{-1}) in a two-year field trial. Experiment 2 was aimed to assess the effect of the split distribution of prilled urea fertilizer in comparison with the application of nitrification inhibitor (DMPP) containing urea fertilizer, broadcasted at sowing.

Spinach yield, yield quality (nitrate – NO_3^- – and carotenoids content), N-use efficiency and risk of soil nitrate (NO_3^--N) leaching were evaluated. The processing spinach yielded 37.8 and 3.6 t ha^{-1} of fresh and dry yield, respectively (average of the two experiments). Fresh and dry yield among the fertilizing treatments were similar. Also the β-carotene and the lutein content of spinach leaves (19.5 and 38.1 mg kg^{-1}, respectively) were not affected by the N fertilizer dose. Conversely, the N dose strongly influenced the NO_3^- content of the leafy vegetable tissues (1286 mg kg^{-1} on average, 58% lower than the limits imposed by the EC regulation). As expected, the different rainfall pattern influenced both the leaf NO_3^- content and the risk of soil NO_3^--N leaching. The results achieved demonstrated that, in order to get a favorable trade-off, among yield, yield quality, N-use efficiency and environmental impact, the processing spinach growers of the Foggia plain area should be encouraged to apply 225 kg N ha^{-1} as maximum fertilization rate. Also, the split urea fertilizer application appeared as the more effective strategy for N fertilization of overwinter spinach in comparison with the use of the nitrification inhibitor containing urea fertilizer, being the last strategy not able to adequately match the N crop demand.

1. Introduction

Processing spinach (*Spinacia oleracea* L.) is widely cultivated in the Italian plains at different latitudes. In particular, in Southern Italy a large area of spinach cultivation is localized in the Foggia plain (Apulia Region) under a typical Mediterranean climate. In this area, the processing spinach cultivation begins in August with the preparation of the seedbed of the early cropping cycles. The crop is then harvested, 45–60 days after sowing. The subsequent sowings may be carried out until early December. In this period, because of the relative low temperatures, the spinach crop grows slowly, overwintered, and is harvested in February or March, generally 100–120 days after sowing. Moreover, harvests in April and early May are obtained thanks to the sowings carried out after the coldest winter period (i.e., late February–March). The processing industry is then continuously provided with spinach to be processed for a long-lasting 6–7 months period (i.e., from October to early May). This allows the processing companies to reduce the fixed costs, thus contributing to keep their activity economically sustainable (Fontana, personal communication). However, the overwintering spinach cropping cycles present agronomically and environmentally problematic issues concerning their nitrogen (N) fertilization and leaching losses of soil nitrate (NO_3^--N). In fact, the unfavorable winter climate, characterized by relative low temperatures, the unevenly distributed rainfalls which increase the N leaching risks, the scarce ability of spinach to efficiently use N because of its shallow rooting system, and the need of farmers to obtain an adequate yield and a proper quality level, make it particularly difficult to take correct decisions about the dose, the timing and the

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typology of N fertilizer applications to this crop (Schenk et al., 1991; Elia et al., 1998).

In order to overcome the above mentioned issues, two alternative strategies have been identified by the spinach farmers of the Foggia area so far. They are based on the use of various doses and typologies of N fertilizer. Following the first strategy the (relatively cheap) prilled urea fertilizer is used, the total dose of which is split in three times (at sowing, at the 2nd true leaves stage and at the beginning of the leaves elongation stage) during the spinach cropping cycle. The second strategy is based on the use of slow and controlled-release fertilizers, the total dose of which is applied in one solution, at sowing time.

According to Rodrigues et al. (2010), slow and controlled-release fertilizers are those that delay initial availability, or extend the time of continued availability, by means of a variety of mechanisms. The microbially degradable N products, such as urea-formaldehydes and other urea-aldehyde compositions are commonly referred to as slow-release fertilizers, whereas coated or encapsulated products (sulphur coatings, polymer coating, etc.) are known as controlled-release fertilizers. Moreover, stabilized fertilizers refer to those which are modified during production with a nitrification inhibitor (Trenkel, 2007), such as 3,4-dimethylpyrazole phosphate (DMPP) and dicyandiamide. They retard the nitrification and have been proposed to reduce nitrate accumulated by vegetables grown in field conditions (Irigoyen et al., 2006).

Despite the above described alternative strategies are thought to be potentially able to enhance crop productivity and reduce environmental pollution, scientific evidences about their effectiveness for spinach N fertilization in Southern Italy are missing. The present study was aimed to identify the best practice for overwinter spinach N fertilization, defining the proper fertilizer dose, typology of application at the right time, at a local and regional scale. The findings could also help processing spinach growers to modulate N management strategies under similar circumstances, under Mediterranean climatic conditions. To reach this objective, the effects of alternative N fertilization options were evaluated in terms of spinach yield, yield quality, N-use efficiency and risk of N leaching.

2. Materials and methods

2.1. Site and climate

Two field trial experiments (hereafter reported as experiments 1 and 2) were carried out in Foggia (41°28′ N, 15°34′ E), in a typical plain of Southern Italy, the Apulian "Tavoliere", during the 2008/2009 and 2009/2010 cropping seasons (from now on indicated as 2008 and 2009, respectively).

The soil is a Vertisol of alluvial origin, classified by Soil Taxonomy-USDA as Fine, Mesic, Typic Chromoxerert. It has a clay loam texture (sand 44%, silt 20% and clay 36%), sub-alkaline pH (7.5), a sufficient amount of organic matter (2.1%) and total N (1200 mg kg^{-1}). It is largely representative for the soils in the area.

The climate is "accentuated thermomediterranean", as classified by UNESCO-FAO (1960), with winter temperatures which can fall below 0 °C over night, summer temperatures which can rise above 40 °C and rainfall unevenly distributed during the year, being concentrated mainly in the winter months. Particularly, the weather during the trial period was characterized by great variability compared to the long-term period (1952–2005).

2.2. Experiment 1: setup, treatments and measurements

The first experimental trial was a two-year field trial. Overwinter processing spinach (*Spinacia oleracea* L., cv. Comoros) was sown at the end and at the beginning of November in 2008 and 2009, respectively, in a completely randomized block experimental design with four replications. The following four N fertilizer doses were compared: 0 (not fertilized control), 150, 225, and 300 kg N ha^{-1}. In each fertilizing treatment, subdividing the total amounts in equal parts, the prilled urea (N 46%) was broadcasted in three times: before sowing, at the stage of second couple of leaves and at fast growing stage. The P fertilizer (50 kg P_2O_5 ha^{-1}) was applied at the time of soil ploughing, whereas no K fertilizer was broadcasted, since the soil contained a good amount of this element in the exchangeable fraction (>600 mg kg^{-1}) (Montemurro et al., 2005).

At harvest (101 and 105 days after sowing (DAS) for year 2008 and 2009, respectively), one square meter of plants was sampled and tested for yields (fresh and dry matter weight), quality (percentage of dry matter and plant NO_3^- content) and plant N uptake. The collected samples were weighed and dried for 48 h at 70 °C to determine their dry weight. Furthermore, plant NO_3^- content (Nitracheck®, MERCK) and the total N content (Kjeldahl method) were determined, allowing the calculation of total N uptake (N content × biomass dry weight). On the basis of these measurements, the following N efficiency parameters were calculated.

1. Nitrogen use efficiency "NUE" (ratio of yield to N applied), in kg kg^{-1}.
2. Nitrogen recovery efficiency "NRE" (ratio of (N uptake by the fertilized plot – N uptake by the control, not fertilized plot) to N applied to the fertilized plot), in kg kg^{-1}.

These indexes were defined according to Delogu et al. (1998), Lòpez-Bellido et al. (2005), Montemurro et al. (2006) and Canali et al. (2010).

Soil nitrate-N (NO_3^--N recorded at 0–30 cm soil depth) was also determined in each experimental trial at harvest. NO_3^--N was extracted by 2 M KCl (1:10, w/v) and measured by a continuous flow colorimetry according to Henriksen and Selmer-Olsen (1970). Losses of ammonia by volatilization have not been assessed, both for experiments 1 and 2, because during the cropping cycles the experimental conditions (i.e., low soil temperatures and adequate soil moisture typical of winter months) the losses were expected to be negligible.

2.3. Experiment 2: setup, treatments and measurements

The second field experiment was carried out in 2008, using a factorial design with four replications. The first factor was the typology of fertilizers: (i) prilled urea (N 46%), and (ii) a controlled release fertilizer composed of urea combined with 1% of the 3,4-dimethylpyrazole phosphate (DMPP) nitrification inhibitor (also known with the ENTEC® trade registered brand). The second factor was the fertilizer dose and the following four levels were compared: 0 (not fertilized control), 150, 225, and 300 kg N ha^{-1}. The controlled release fertilizer was applied in one time at sowing, while the urea fertilizer was broadcasted, similarly to the first experiment, in three times: before sowing, at the stage of second couple of leaves and at fast growing stage. Similarly to experiment 1, the P fertilizer (50 kg P_2O_5 ha^{-1}) was applied at the time of soil ploughing and no K fertilizer was applied. The spinach (cv. Comoro) was sown at the end of November and harvested at the beginning of March, 101 days after sowing (DAS).

Measurements were carried out with the same methodologies above described for the experiment 1. Moreover, lutein and the β-carotene content of the spinach leaves at harvest (Hart and Scott, 1995) and the SPAD index (SPAD-502 chlorophyll meter, Konica Minolta) of the uppermost fully expanded leaves (Liu et al., 2006) were assessed at harvest.