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Research Paper

Impact of irrigation regime and nitrogen rate on yield, quality and water use efficiency of wild rocket under greenhouse conditions

M.I. Schiattone[a,*], R. Viggiani[a], D. Di Venere[b], L. Sergio[b], V. Cantore[b], M. Todorovic[c], M. Perniola[a], V. Candido[a]

[a] School of Agriculture, Forest, Food and Environmental Sciences, University of Basilicata, Viale dell'Ateneo Lucano, 10, 85100 Potenza, Italy
[b] Institute of Sciences of Food Production, National Research Council (CNR-ISPA), Via Amendola, 122/O, 70125, Bari, Italy
[c] Mediterranean Agronomic Institute of Bari CIHEAM-IAMB, Via Ceglie, 9, 70010 Valenzano (BA), Italy

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ABSTRACT

In Italy, the cultivation of wild rocket is still rising due to the increase of the market of minimally processed vegetables that requires innovative and high quality products. The present study focused on the interactive effect of irrigation regimes (IR) and nitrogen (N) supply on yield, water use efficiency (WUE), nitrogen use efficiency (NUE), morphological and quality parameters of wild rocket. The research was carried out on four crop cycles during autumn-spring season in Basilicata region, Southern Italy, on wild rocket grown in a plastic greenhouse. Four IR (corresponding to 75, 100, 125 and 150% of crop evapotranspiration, and labelled respectively as I_{75}, I_{100}, I_{125} and I_{150}) and two N levels (60 and 120 kg ha^{-1}), were compared. The irrigation and N levels affected production traits of wild rocket. The highest yield was obtained by I_{100}, while 8% and 6% decrease in yield was observed with I_{75} and I_{150}, respectively. The greater yield was obtained with the higher N rate, to which contributed firstly the leaf number and secondly the leaf size. However, the higher N dose provided higher leaf nitrate content. Moreover, in conditions of greater water stress occurring in the last two crop cycles of I_{75}, higher N rate adversely affected yield. Lower water and N supply improved phenols, carotenoids and antioxidant activity in rocket leaves. Both yield and biomass WUE increased in water shortage conditions (I_{75}) at 1st crop cycle. Thereafter, both parameters tended to decrease because of the increase of water shortage, indicating that biomass and marketable yield losses were proportionally greater than the amount of water used by crops. Higher N rate improved WUE, but reduced NUE. The latter parameter was higher in water shortage conditions. Thus, adequate water and N supply are critical factors to ensure economically sustainable production levels and high quality features of wild rocket.

1. Introduction

Wild rocket [*Diplotaxis tenuifolia* (L.) DC.], belonging to *Brassicaceae* family, grows wildly in the Mediterranean basin up to 1000 m altitude. The species is naturally present in both cultivated and uncultivated areas, preferably on sandy and calcareous soils, along the edges of the roads and abandoned areas (Bianco, 1995). In the last decades, wild rocket has become popular and widely cultivated in greenhouses and open fields. Its production as 'baby leaf' crop steadily increased in the fresh-cut industries. In Italy, several species of the genus *Diplotaxis* are consumed as vegetables since ancient times. The leaves, unmistakable for its characteristic aroma and piquant flavor, can be eaten raw in salads or cooked in many recipes. In comparison to other leafy vegetables, wild rocket has high content of fiber and iron (Barillari et al., 2005), and in traditional medicine is used for different purposes: anti-inflammatory, astringent, purifying, diuretic, digestive, emollient, tonic, stimulant, laxative, anti-inflammatory for colitis and anti-scorbutic (De Feo and Senatore, 1993). In addition, it should be emphasized the peculiarity of this species for the high content of secondary metabolites like ascorbic acid, phenols, carotenoids and glucosinolates (Cavaiuolo and Ferrante, 2014; D'Antuono et al., 2009; Di Venere et al., 2000), to which important bioactive properties (e.g., antioxidant, antitumour, etc.) are often ascribed. Actually, the positive health effects as anticancer agents (Ramos-Bueno et al., 2016) as well as the influence of growing conditions (e.g., nitrogen availability, light intensity, etc.) (Disciglio et al., 2017) on their content in the rocket leaves have been widely demonstrated (Bonasia et al., 2017; Jin et al., 2009; Weightman et al., 2012).

From a qualitative point of view, as for many leafy vegetables, wild rocket has the undesired problem of the accumulation of high amounts

* Corresponding author.
E-mail addresses: maria.schiattone@unibas.it, mary.schiattone@libero.it (M.I. Schiattone).

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of nitrate (Santamaria et al., 2002; Weightman et al., 2012), responsible for toxic effects to the human body, especially as agent of methemoglobinemia and precursor of carcinogenic compounds such as nitrosamines (Santamaria, 1997). Therefore, nitrates are considered antinutrients, and their content in vegetables has become an important element of qualitative nutritional and product discrimination, regulated by European legislation. However, there are also experimental evidence showing beneficial effects of nitrates and nitrites on cardiovascular diseases (Machha and Schechter, 2012). The European Commission (EC) Regulation n. 1881/2006 established the maximum limits of nitrates content in lettuce and spinach (EC, 2006), while the EC Regulation n. 1258/2011 introduced limitations also for rocket and cereal-based food (EC, 2011). Furthermore, these thresholds change from species to species and differ for the season and cultivation environment (open field or greenhouse). Rocket, for example, has to be commercialized with a nitrate content not higher than 6000 mg kg^{-1} FW (fresh weight) in summer-growing or 7000 mg kg^{-1} FW in winter-growing.

Various factors play an important role on the nitrate content of vegetables, especially: i) the genotype (e.g., *Brassicaceae* and *Chenopodiaceae* are $N{-}NO_3$ hyperaccumulators) (Santamaria et al., 2002), ii) environmental conditions involved in the activity of nitrate reductase (NR), the enzyme that governs the reduction of nitrate in plant organs (Bonasia et al., 2017; Weightman et al., 2012), and iii) cultivation techniques as nitrogen fertilization and water availability (Santamaria et al., 1999; Weightman et al., 2012). Water scarcity may cause NO_3^- accumulation by reducing NR activity. Nevertheless, NR activity reduction related to water deficit is not always correlated to an increase in nitrate leafy content, as its accumulation is also governed from absorption of nitrogen by roots that can be reduced in presence of water stress (Correira et al., 2005). In addition, water scarcity, combined with high nitrogen (N) level, can determine salt stress conditions, in which plants absorb nitrate, together with other ions, as osmotic regulators for adapting to such type of stress (Santamaria et al., 1997). Indeed, nitrates are highly accumulated in the vacuole, where they exert functions in the osmotic regulation especially in absence of other important osmotic regulators (e.g., sugars, sodium, chloride) (Cavaiuolo and Ferrante, 2014). Moreover, it was observed that plant nitrate content, such as for the water stress, increases also with the high soil humidity (Tamme et al., 2010).

As for many crops, the main agronomic factors that influence yield and quality of wild rocket are the availability of water and nutrients, especially N. Agronomic management of these factors requires special attention in light of the environmental effects that their use entails. In particular, chronic shortage of water in many hot arid climate areas, like Southern Italy, requires thrifty use, as well as the risk of aquifer pollution by N leaching requires a careful irrigation management and N supply.

Water shortage reduces yield of many leafy vegetables as a result of a concomitant decline of leaf number per plant and leaf size (Bozkurt et al., 2009; Mahmood et al., 2004; Mirdad, 2009). Usually, *D. tenuifolia* grows wildly in poor soils in water shortage conditions. It assumes a xeromorphic habitus that allows the survival and reproduction, but it produces small and fibrous leaves, valuable for recreational purposes, but not useful for commercial production because of its heterogeneity. Although wild rocket is well suited to be grown in dry land, in order to improve yield and quality for commercial purpose it is necessary to cultivate it with adequate water availability. In fact, water availability, in addition to affecting yield, can have a very important role in key qualitative characters (e.g., antioxidant content) (Stefanelli et al., 2010). But, in view of increasing water demand by other sectors and expected reduction of water availability in the future, it is necessary to adopt water management strategies aiming at water saving while maintaining satisfactory levels of production and increasing water use efficiency (WUE) (Costa et al., 2007; Giuliani et al., 2016; Lovelli et al., 2017).

Wild rocket, like other leafy vegetables cultivated for commercial purposes, requires an adequate nitrogen supply to ensure high qualitative levels and production standards. Nitrogen availability in leafy vegetables affects many qualitative parameters, as the content of dry matter, nitrate, vitamin C and polyphenols, leaf green color, crunchiness, shelf-life (De Pascale et al., 2013). Stefanelli et al. (2010) found for many vegetables a negative relationship between N level and phenol, glucosinolates and vitamin C content, and a positive relationship with chlorophyll content. Therefore, in consideration also of the problems due to the accumulation of nitrates of this species, proper management of nitrogen fertilization is a critical element to obtain high quality product and to improve nitrogen use efficiency (NUE). Considering the increasing economic importance of wild rocket in Italy and the crucial role of water and N availability for determining high yield and good quality, a great attention should be paid to the optimization of irrigation management and N fertilization, in light also of the excessive supply by farmers and environmental impact of these techniques. The availability of water and nitrogen acts interactively on production and quality (Hu and Schmidhalter, 2005) as observed for example on spinach and tomato crops (García et al., 2000; Zhang et al., 2015). Instead, there are no experimental findings in this regard on the wild rocket.

The novelty of this study is that it focussed on the combined effect of irrigation regime and N level on yield, quality, morphological features, WUE and NUE of wild rocket under unheated plastic greenhouse – the technique usually used for wild rocket cultivation during the autumn-spring season – in light of the lack of this type of studies on this species. Moreover, a special attention was paid on the impact of cultivation practices on the quality of product, which is of notable importance for this type of crop.

2. Materials and methods

2.1. Experimental site characteristics

The research was carried out in the private farm 'Troyli' at Policoro (MT), Southern Italy (40°22′N, 16°62′E; 150 m a.s.l.), during 2014–2015 growing season (5 November – 27 April), in an unheated plastic greenhouse, covered by an EVA 200 μm thick film.

This site is characterized by sub-humid climate according to the De Martonne classification (Cantore et al., 1987). The main agro-meteorological variables, including air temperature, relative humidity, solar radiation, and reference evapotranspiration (ETo) from an atmometer (Model A, ETgage Co. USA), were measured. Data were collected by the electronic system operated through a data-logger connected via modem to a PC.

The soil, deeper than 1 m, is a Typic Haploxeralfs fine loamy, mixed, superactive, thermic (Cassi and Viviano, 2006), whose physical and chemical characteristics were: sand (2 > Ø > 0.02 mm) 44.1%, silt 20.0%, clay (Ø < 2 μ) 35.9%; pH 7.2; total N (Kjeldahl method) 1.53 g kg^{-1}, available P_2O_5 (Olsen method) 56.0 mg kg^{-1}, exchangeable K_2O (ammonium acetate method) 372 mg kg^{-1}, organic matter (Walkley-Black method) 13.8 g kg^{-1}, total limestone 19.1 g kg^{-1}, active limestone 9.8 g kg^{-1}, saturated paste extract electrical conductivity (ECe 2:1) 0.64 dS m^{-1}, ESP 1.9%, bulk density 1.25 kg dm^{-3}, soil moisture at field capacity 33.2 cm^3 cm^{-3} and at wilting point (−1.5 MPa) 22.6 cm^3 cm^3.

2.2. Climate trend

Trend of minimum and maximum temperature (T_{min}, T_{max}) was typical of the area concerned by the experiment (data not shown). Temperature was decreasing from sowing time until the end of February and increasing thereafter. T_{max}, of about 22 °C in the period of sowing, dropped to below 20 °C in the days before the first harvest (December 19). Thereafter it decreased gradually fluctuating around 15 °C during the period of the second harvest (February 23). It has remained almost unchanged at around 14–16 °C until the third harvest