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Improved yield and nutrient efficiency in two globe artichoke genotypes by balancing nitrogen and phosphorus supply

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Abstract Efficient fertilization is a central topic in sustainable agriculture since fertilization strongly influences both crop performances and environmental impact. In several Mediterranean regions, globe artichoke fertilization is still empirically oriented toward nitrogen overdressing and insufficient phosphorus supply. To date, there is a lack of systematic research on the relationships between nitrogen and phosphorus fertilizations, especially in terms of nutrient efficiency. Here, in a 2-year experiment, we studied the effects of two phosphorus fertilization rates, 50 and 150 kg P₂O₅ha⁻¹, and four nitrogen fertilization rates, 0, 150, 300 and 450 kg Nha⁻¹, on earliness, yield characteristics and nutrient efficiency indices of two globe artichoke genotypes: the traditional vegetatively propagated ‘Violetto di Sicilia’ and the modern ‘seed’-propagated ‘Opal F₁’. The nutrient efficiency indices included partial factor productivity of nitrogen (PFP_N), total factor productivity (TFP) and nitrogen agronomic efficiency (N_{AE}). Results show that the highest phosphorus rate allowed to reduce nitrogen supply from 450 to 300 kg ha⁻¹ without compromising earliness or yield of the crop. The highest phosphorus rate also increased PFP_N up to 6.9 kg heads dry weight ha⁻¹ kg⁻¹ and N_{AE} up to 2.5 Δ kg dry weight ha⁻¹ kg⁻¹, thus indicating a better nitrogen utilization of the crop, especially at lower

doses. ‘Opal F₁’, as compared to ‘Violetto di Sicilia’, showed higher PFP_N of 8.1 versus 5.2 kg heads dry weight ha⁻¹ kg⁻¹ and TFP of 4.0 versus 2.4 kg heads dry weight ha⁻¹ kg⁻¹, especially at low nitrogen supplies. We conclude that balancing nitrogen and phosphorus supplies, together with the adoption of globe artichoke genotypes characterized by more efficient utilization of soil mineral nutrients, are effective tools to promote both yield performances and a more sustainable nitrogen fertilization of the crop.

Keywords *Cynara cardunculus* L. · Mineral fertilization · Earliness · Heads number · Head weight · Crop sustainability

1 Introduction

The growing utilization of nitrogen (N) fertilizers, starting from the early 1960s, has become one of the primary concerns in sustainable agriculture both in developed and developing nations, given the role of N as a pollutant involved in ecosystems, biodiversity and food safety deterioration (Ehaliotis et al. 2010; Spiertz 2010). On the other hand, because of the central role of this macronutrient in determining crop growth and yield capability, N fertilization is perceived as essential in those agricultures not devoted merely to subsistence production (Bhattacharyya et al. 2008; Gonzalez-Dugo et al. 2010). With a view to ensuring high and stable crop yield in a sustainable way, today it is imperative to optimize the efficiency of using chemical N fertilizers in farmland. According to White and Brown (2010), there are two paths to achieve these targets: an agronomical one, aiming at improving fertilization practices, and a genetic one, aiming at spreading the cultivation of genotypes that acquire soil mineral elements more effectively.

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Mediterranean soils are largely characterized by high amounts of native potassium (K), but low organic matter and, therefore, low N reserves and mineralization potential (Ryan 1998). As a consequence, N fertilization is considered indispensable to improve crop productivity (Ryan et al. 2008). On the other hand, the high limestone content characterizing many soils of this region is often at the root of the strong positive responses of the crops to phosphorus (P) fertilization (Ryan et al. 2008). This leads to pivotal practical applications for N fertilization management because crop requirements may show a strong dependence upon the combined effect of P and N available in the soil (Zubillaga et al. 2002).

In Southern Europe, globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] represents an important resource for the agricultural economy (Mauro et al. 2009). The species is a herbaceous, high N-demanding perennial plant, belonging to the Asteraceae family, whose edible inflorescences (heads or capitula) represent a minority fraction of the total aboveground dry matter (Elia and Conversa 2007). Over recent years, thanks also to its reputation as a functional food (Pandino et al. 2010), globe artichoke cultivation is being grown in many parts of the world, especially in Asia (mainly in China, 10.0 kha), South America (Peru, Chile and Argentina, with 7.7, 5.0 and 4.7 kha, respectively) and North Africa (Egypt and Morocco, with 7.7 and 4.1 kha, respectively; FAOSTAT 2008). Italy is the leading artichoke producer worldwide (50.0 out of 133.0 kha cultivated in the World and a mean annual production of about 480 kt of heads), followed by Spain (16.0 kha and 200 kt) and France (9.5 kha and 45 kt; FAOSTAT 2008). In Italy, the crop is mainly present in irrigated farmland of southern regions (Apulia, Sicily, Sardinia) through the cultivation of ancient, vegetatively propagated genotypes (e.g. ‘Violetto di Sicilia’, ‘Violetto Spinoso di Palermo’, ‘Violet de Provence’) which, despite their relatively low yields, are able to ensure high economic gains, most of all thanks to their marked earliness and long productive cycle (from October–November to April; Mauromicale et al. 2004). Overall, the species is usually grown on coastal plains, on a wide range of soil types (Elia and Conversa 2007), but often characterized by poor N and available P content, and moderate to high K and calcium content. Globe artichoke growers mainly adopt N fertilization, which is commonly reputed to be the primary tool to increase both earliness and yield of the crop, while P fertilization, in order to reduce the cultural costs, is often effected at reduced rates. This leads to irrational fertilization management of the crop, especially regarding N, for which application rates higher than 700 kg ha⁻¹ are frequently applied (Magnifico 1987). On the other hand, unlike for K fertilization, the experimental results obtained in different productive areas show many discrepancies in the optimal

application rates of P fertilizers, as they strongly depend on soil characteristics, cropping practices, climatic conditions and genotypes (Elia and Conversa 2007). With reference to this last aspect, the recently developed ‘seed’-propagated cultivars show a better utilization of soil mineral and water, so virtually allowing the implementation of more sustainable fertilization programs (Cosentino and Mauromicale 1990; Basnizki and Zohary 1994; Mauromicale and Ierna 1995, 2000). Despite some contributions dealing with globe artichoke response to mineral fertilization (e.g. Khayyo et al. 2004; Foti et al. 2005; Rincón et al. 2007), no attempts have been focused to date on defining the N and P relationships in this crop, especially in terms of nutrient efficiency, which, instead, may represent a more useful framework toward a sustainable fertilization practice for this crop.

The goal of the present study was to evaluate the effects of different N and P fertilization rates, as well as the interaction of both mineral nutrients, on earliness, yield characteristics and nutrient efficiency in two different genotypes of globe artichoke, with the aim of reaching a more sustainable fertilization management of globe artichoke crop in a Mediterranean environment.

2 Materials and methods

2.1 Experimental site

A field experiment was conducted over two growing seasons (2003/2004 and 2004/2005) on the coastal plain South of Siracusa (South-eastern Sicily, 37°03'N, 15°18'E, 15 m a.s.l.), an area where globe artichoke cultivation is common. The local climate is characterized by mild wet winters and warm dry summers; winter frosts are rare (two events over 30 years). The moderately deep soil was a Calcixerollic Xerochrepts (USDA, Soil Taxonomy), which, at the beginning of the experiment comprised 30% clay, 25% silt, 45% sand, 2% organic matter, 21.7% total limestone, 1.6‰ total nitrogen, 68 kg ha⁻¹ assimilable P₂O₅ and 539 kg ha⁻¹ exchangeable K₂O. The soil pH was 7.8, its moisture capacity was 29% (0.34 m³ m⁻³) of dry soil, and its wilting point was 11% (0.13 m³ m⁻³). All soil analyses were performed according to procedures approved by the Italian Society of Soil Science (Società Italiana Scienza del Suolo 1985).

2.2 Experimental design and crop management

A split plots design with four replications was adopted, involving two phosphorus fertilization rates (50 and 150 kg ha⁻¹ of P₂O₅, hereafter referred to as P₅₀ and P₁₅₀, respectively) as the main plots, four N fertilization rates (0,

150, 300 and 450 kg ha⁻¹ of N, hereafter referred to as N₀, N₁₅₀, N₃₀₀ and N₄₅₀, respectively) as sub-plots and two globe artichoke genotypes (the Italian traditional ‘Violetto di Sicilia’ and the hybrid cultivar ‘Opal F₁’) as sub-sub-plots. ‘Violetto di Sicilia’ is an autochthonous varietal type, which has represented the main cultivated germplasm in South Italy for decades, owing to its earliness and adaptability (Mauromicale and Ierna 2000; Portis et al. 2005). In the Mediterranean environment, its productive period starts in October–November and ends in April. Moreover, it shows similar biological characteristics to other widespread cultivars in Europe, such as ‘Violet de Provence’ and ‘Blanca de Tudela’. ‘Opal F₁’ is a commercial cultivar released by *Nunhems* (Nunhems BV, Haelen, the Netherlands), characterized by high productivity, contemporary harvests and good quality of heads for fresh consumption (Calabrese et al. 2004). The productive period of this cultivar starts in April and ends in May. These genotypes were chosen because of their different propagation methods: vegetative by ‘ovoli’ (dormant offshoots) in ‘Violetto di Sicilia’, by ‘seeds’ (achenes) in ‘Opal F₁’, since this strongly influences the globe artichoke root growth in the first stages and the overall rhizosphere dimension of the plant (Cosentino and Mauromicale 1990). Fifty-day-old seedlings at the stage of three to four true leaves (‘Opal F₁’) and pre-sprouted ‘ovoli’ (‘Violetto di Sicilia’) were transplanted in the field on August 10, 2003 in a 0.80×1.25-m format (10,000 plant ha⁻¹). Each sub-sub-plot consisted of 30 plants. Prior to transplanting, tillage consisted of a 25-cm depth ploughing followed by harrowing, while at the end of the first season (early June) plants were mowed at ground level. In the second season, the dried, 1-year-old crop was awakened on August 5, 2004 by drip irrigation until field capacity. In both growing seasons, drip irrigation was supplied starting from transplanting by providing 100% of maximum evapotranspiration (net of rain), when accumulated daily evaporation, from an unscreened class A-Pan evaporimeter situated near the crop, reached 40 mm. Fertilization with P and K was done before transplanting (season I) or crop re-growth (season II), incorporating into the top 20-cm soil layer triple superphosphate (46% P₂O₅) and 200 kg ha⁻¹ K₂O potassium sulphate (51% K₂O), respectively. N was applied by liquid fertilization eight times (in equal amounts every 25 days from late August until early December, and from mid-February until late April) in each growing season. A liquid fertilizer (Nitro-plus32[®]) was used with a 32% of N concentration: 8% as nitrate, 8% as ammonium and 16% as urea. In each growing season, weeding and pest management were conducted as per local custom, and lateral offshoots were removed twice, in early November and mid-February, leaving only one offshoot per plant. Plants of both genotypes were not treated with gibberellic acid.

2.3 Data collection

Meteorological conditions (maximum and minimum air temperature, relative humidity, rainfall) were monitored during the trial by a meteorological station (Mod. Multi-recorder 2.40; ETG, Firenze, Italy) sited at the experimental field. Heads (main and secondary) were harvested on a weekly (autumn and winter) or 4 days (spring) basis at marketable stage and weighed without floral stems to determine their fresh weight. Then, subsamples of 20 main and secondary heads per plot were oven-dried at 105°C for 72 h to determine their dry weight. At the end of season II, five plants per sub-sub-plot were eradicated from the soil leaving the roots as undamaged as possible. Roots were then detached from the other plant parts, gently washed in tap water to remove soil residues and weighed. Five root samples per sub-plot, 50 g each, were oven-dried at 105°C until constant weight, then reweighed in order to determine the root dry weight per plant.

In both seasons, the following variables were calculated: earliness (as an index of commercial competitiveness of the crop, and expressed as number of heads collected at 31 December and 31 March in ‘Violetto di Sicilia’ and ‘Opal F₁’, respectively, according to their different timing of floral induction and head ripening), total yield, expressed both as t fresh weight (FW) of heads ha⁻¹, and number of heads ha⁻¹. The efficiency of N and P fertilization was calculated in terms of factors productivity, which were calculated according to the following equations: $PFP_N = Y_N/N_F$ $TFP = Y_{NPK}/NPK_F$ where PFP_N and TFP are the partial factor productivity of nitrogen and total factor productivity (nitrogen+phosphorus+potassium), respectively; Y_N and Y_{NPK} are the heads yield (expressed as kg ha⁻¹ on a dry weight basis) of the N- and N+P₂O₅+K₂O-fertilized plots, respectively; N_F and NPK_F represent the amount of N and N+P₂O₅+K₂O applied units, respectively (expressed as kg ha⁻¹).

Moreover, for nitrogen fertilization, the agronomic efficiency (N_{AE}) was calculated according to the following equation $N_{AE} = (Y_N - Y_0)/N_F$ where Y_N represents the heads yield of the N-fertilized plot (expressed as kg dry weight ha⁻¹), Y_0 is the heads yield of the N-unfertilized plot (control), and N_F represents the amount of N applied (expressed as kg ha⁻¹) in fertilized plots.

2.4 Statistical analysis

Data collected were first submitted to Bartlett’s test to check the homoscedasticity, then analyzed through a four-way (phosphorus rate × nitrogen rate × genotype × season) factorial analysis of variance (ANOVA). Commercial earliness, for each genotype, was subjected to a three-way (phosphorus rate × nitrogen rate × season) ANOVA,

according to the different harvest period of the two genotypes tested. Provided that the F test was significant, means were separated on the basis of Fisher's protected least significant difference test. All calculations were performed using CoStat[®] version 6.003 (Cohort Software, Monterey, CA, USA).

3 Results and discussion

3.1 Weather conditions

Total rainfall in the 2003–2004 growing season was rather low (328 mm), the majority of which (211 mm) fell mostly between October and March. The 2004–2005 growing season was more rainy, as the rainfall amount was 572 mm, and almost 80% of it (440 mm) fell between October and February. Both growing seasons were characterized by similar maximum and minimum temperatures, which progressively decreased passing from August (on the average of both growing seasons 32.0°C and 20.6°C, respectively) to January (15.3°C and 7.8°C, respectively), and thereafter increased until May (24.3°C and 15.4°C, respectively; data not shown).

3.2 Earliness

N supply strongly affected earliness of both genotypes (Table 1). As compared to control (N_0), earliness increased up to N_{300} in 'Violetto di Sicilia' (from 26,700 to 34,600 heads ha^{-1} harvested at 31 December), and up to N_{150} in 'Opal F₁' (from 12,400 to 18,900 heads ha^{-1} harvested at 31 March) and also showed a significant decrease at higher N supplies (Table 1). These results substantially confirm previous researches conducted in different productive areas, which found the 142–285 kg Nha^{-1} to be the optimal range for improving globe artichoke earliness (Elia and Conversa 2007), highlighting to a strong genetic component influencing the most appropriate N dose able to optimize the earliness of the crop. The highest P supply did not affect earliness per se (Table 1), but it significantly modified the response of both genotypes to the N supply (Fig. 1). In 'Violetto di Sicilia' at P_{50} , earliness increased from N_0 to N_{150} (from 25,000 to 30,100 heads ha^{-1} harvested at 31 December) and from N_{300} to N_{450} (from 31,000 to 36,000 heads ha^{-1} harvested at 31 December), while at P_{150} it increased from N_0 to N_{300} (from 28,500 to 37,900 heads ha^{-1} harvested at 31 December), then sharply decreased at N_{450} (25,800 heads ha^{-1} harvested at 31 December; Fig. 1a). In 'Opal F₁', the P_{150} supply significantly improved earliness at N_{150} (19,800 heads ha^{-1} harvested at 31 March) as compared with the same N supply at P_{50} (16,900 heads ha^{-1} harvested at 31 March),

Table 1 Earliness (000 heads per hectare harvested at 31 December and 31 March in 'Violetto di Sicilia' and 'Opal F₁', respectively) as affected by the main factors

Treatment	Violetto di Sicilia	Opal F ₁
Phosphorus rate		
P_{50}	30.5 a	15.3 a
P_{150}	31.5 a	15.7 a
F	0.6 ^{NS}	0.3 ^{NS}
Nitrogen rate		
N_0	26.7 c	12.4 c
N_{150}	31.9 ab	18.9 a
N_{300}	34.6 a	15.9 b
N_{450}	30.7 b	14.8 b
F	7.0 ^{**}	14.6 ^{***}
Season		
Season I	29.8 a	14.9 a
Season II	32.2 a	16.1 a
F	3.6 ^{NS}	2.7 ^{NS}

F Fisher–Snedecor test, NS not significant

Different letters within each column's factor indicate significance at Fisher's protected least significant difference test ($P \leq 0.05$)

^{**} $P \leq 0.01$; ^{***} $P \leq 0.001$ (significant)

but it also caused a more marked earliness reduction (by up to 5,800 heads ha^{-1} harvested at 31 March) from N_{150} to N_{450} (Fig. 1b). The significant $P \times N$ interaction affecting earliness confirms the primary role of the available P in the soil in influencing the crop response to the N supply (Zubillaga et al. 2002). Under P-limited conditions both genotypes showed higher N demand in order to maximize their earliness, so suggesting an inefficient N use of the crop which is often at the root of its heavy overdressing in ordinary field conditions. Indeed, the highest P rate significantly lowered the N/P ratio of applied fertilization units, able to optimize earliness, regardless of genotype, from 7.5:1 to 1.5:1. This has implications from an environmental point of view, as it suggests that an adequate P supply allows a better N fertilization management of the crop without compromising its earliness, when this trait has a key role for its commercial success.

3.3 Total yield and its components

Total yield was responsive to the N supply, increasing by up to 48% (from 11.1 to 16.4 t FW heads ha^{-1}) from N_0 to N_{300} (Table 2). This resulted from the increase of both, the number of heads per hectare and the weight of main and secondary heads, which, within the same N range, increased by up to 42,700 heads ha^{-1} , 20 g and 22 g, respectively (Table 2). For all these variables, the highest N supply, namely N_{450} , exerted no significant effects (Table 2).

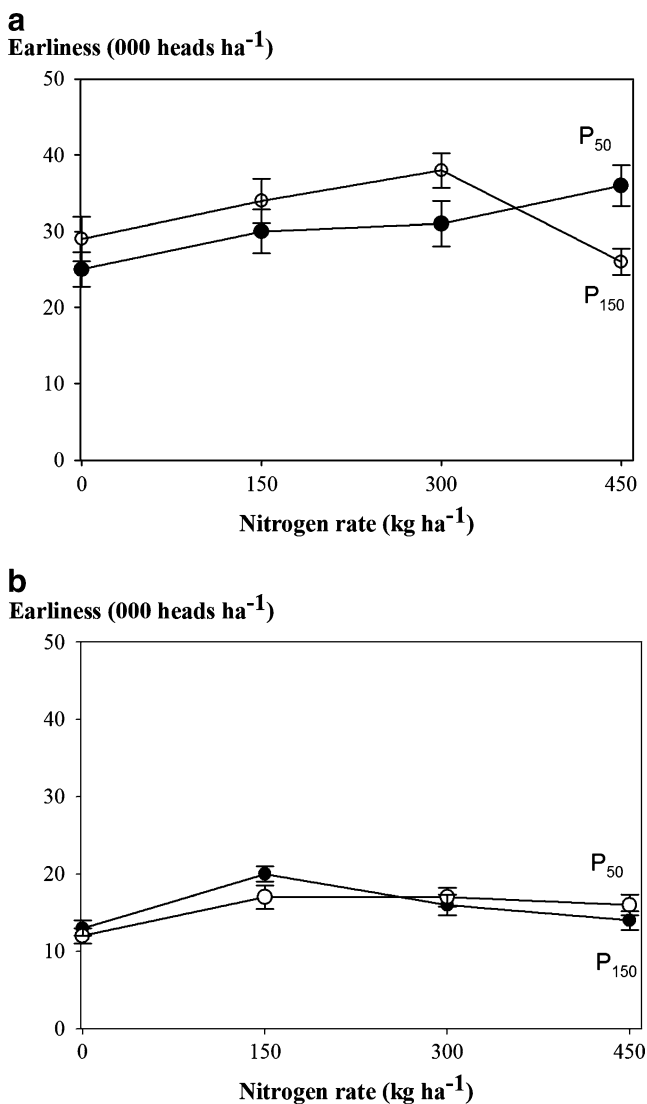


Fig. 1 Earliness in Violetto di Sicilia (**a**) and Opal F₁ (**b**) as affected by 'phosphorus rate x nitrogen rate' interaction. LSD interaction at $P=0.05$ was 3.1 for Violetto di Sicilia and 2.2 for Opal F₁. Vertical bars indicate the standard error of the mean. Solid circle represents P₅₀; open circle represents P₁₅₀

Root dry weight increased from N₀ to N₃₀₀ (from 82 to 127 g per plant) but decreased at N₄₅₀ (Table 2). 'Opal F₁', as compared to 'Violetto di Sicilia', showed higher values of total yield (17.3 vs. 11.6 t FW ha⁻¹) and number of heads per hectare (103,800 vs. 86,100), and weight of heads, main (202 vs. 157 g) and secondary (164 vs. 138 g; Table 2); it also showed the highest root dry weight (113 vs. 91 g per plant; Table 2).

Analysis of variance also showed a significant interaction among N and P supplies as well as among P supply and season on total yield and number of heads per hectare. In the absence of N fertilization, the increase in P supply from 50 to 150 kg ha⁻¹ significantly reduced yield from 12.0 to 10.2 t FW heads ha⁻¹ (Table 3). On the contrary, the

response of both total yield and number of heads per hectare to the growing N supply was more marked at P₁₅₀ than at P₅₀. Indeed, passing from N₀ to N₃₀₀ they showed at P₁₅₀ a steeper increase (from 10.2 to 17.5 t FW ha⁻¹ and from 66,000 to 115,300 heads ha⁻¹, respectively) as compared to the same N doses at P₅₀ (where they increased from 12.0 to 15.2 t FW heads ha⁻¹ and from 68,200 to 104,300 heads ha⁻¹, respectively), but both variables showed a higher decrease as the N supply passed from N₃₀₀ to N₄₅₀ (Table 3). Moreover, at P₁₅₀ both total yield and number of heads per hectare proved a good stability across seasons, while at P₅₀ they showed a significant decrease passing from season I to season II (Table 3).

N and P are known to optimize the plant's photosynthetic, growth and developmental processes, with P playing a central role in determining the efficiency with which solar energy is accumulated and converted into new biomass (Zubillaga et al. 2002). However, the results of this experiment show a marked effect of the available P in the soil on determining the crop's response to the N fertilization. This resulted particularly evident by the strong interaction between P and N in relation to total yield. Indeed, under N-deficient conditions, the highest P rate reduced the total yield of the crop. This could be due to the peculiar synergism between N and P within the plant, since, according to Ashraf et al. (2001), the critical deficiency level of N increases as the P content increases and vice versa. On the contrary, the highest P availability acted to significantly improve the yield response of the crop to the growing N supply, especially within the N₁₅₀–N₃₀₀ interval. As a consequence, a substantial equivalence emerged among the total yield recorded at P₅₀N₃₀₀ and P₁₅₀N₁₅₀, highlighting that, beyond the N₁₅₀ level, increased P supply reduces the plant's need for N; this suggests that up to 150 kg N ha⁻¹ dressing can be avoided by ensuring an adequate available P in the soil without causing total yield decreases. Moreover, under P₅₀ conditions, the yield performance of the crop was reduced across seasons, suggesting that a progressive exacerbation of the P deficiency in the soil could be a component of soil weakness often observed in multiannual globe artichoke cultivations.

Overall, these results show that, in non-limiting P conditions, producers could opt for a significant reduction in the N supply to the crop, from 450 to 300 kg ha⁻¹ in order to maximize and stabilize over seasons the yield of the crop, or from 300 to 150 kg ha⁻¹ to obtain satisfactory yields and ensure, at the same time, a more environment-friendly management of N.

3.4 Nutrient efficiency indices

P and N levels significantly affected almost all the nutrient efficiency indices (Table 2). The highest P supply acted to

Table 2 Bio-agronomical variables and nutrient efficiency indices of globe artichoke as affected by the main factors

Treatment	Total yield (t FW ha ⁻¹)	Number of heads (000 ha ⁻¹)	Heads fresh weight		Root weight (g DW plant ⁻¹)	PFP _N (kg ha ⁻¹ DW kg ⁻¹)	N _{AE} (Δ kg ha ⁻¹ DW kg ⁻¹)	TFP (kg ha ⁻¹ DW kg ⁻¹)
			Main (g)	Secondary (g)				
Phosphorus rate								
P ₅₀	14.3 a	94.0 a	181 a	155 a	87 b	6.4 b	1.0 b	3.3 a
P ₁₅₀	14.6 a	95.9 a	178 a	147 a	117 a	6.9 a	2.5 a	3.1 a
<i>F</i>	0.6 ^{NS}	1.4 ^{NS}	1.0 ^{NS}	2.3 ^{NS}	161.2***	6.1*	125.6***	2.4 ^{NS}
Nitrogen rate								
N ₀	11.1 c	67.1 c	164 c	142 b	82 c	–	–	4.2 a
N ₁₅₀	14.0 b	96.2 b	175 b	145 b	87 c	10.1 a	2.1 a	3.4 b
N ₃₀₀	16.4 a	109.8 a	184 ab	164 a	127 a	5.9 b	1.9 a	2.9 c
N ₄₅₀	16.3 a	106.6 a	194 a	153 ab	112 b	3.9 c	1.3 b	2.4 d
<i>F</i>	74.6***	133.3***	12.4***	4.8 **	4.6**	448.4***	13.8***	107.0***
Genotype								
Violetto di Sicilia	11.6 b	86.1 b	157 b	138 b	91 b	5.2 b	1.8 a	2.4 b
Opal F ₁	17.3 a	103.8 a	202 a	164 a	113 a	8.1 a	1.8 a	4.0 a
<i>F</i>	391.2***	110.2***	155.7***	32.9***	104.1***	287.7***	0.9 ^{NS}	425.0***
Season								
Season I	14.8 a	97.2 a	179 a	145 a	–	6.8 a	1.9 a	3.0 a
Season II	14.1 a	92.7 a	180 a	157 a	–	6.5 a	1.7 a	3.2 a
<i>F</i>	1.7 ^{NS}	0.8 ^{NS}	0.1 ^{NS}	2.8 ^{NS}	–	2.1 ^{NS}	1.6 ^{NS}	2.3 ^{NS}

F Fisher–Snedecor test, *NS* not significant, *PFPN* Partial factor productivity of nitrogen, *NAE* Nitrogen agronomic efficiency, *TFP* Total factor productivity

Different letters within each column's factor indicate significance at Fisher's protected least significant difference test ($P \leq 0.05$)

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$ (significant)

Table 3 Total yield, number of heads and nitrogen agronomic efficiency (N_{AE}) as affected by 'phosphorus rate x nitrogen rate' and 'phosphorus rate x season' interactions

	P ₅₀	P ₁₅₀	P ₅₀	P ₁₅₀	P ₅₀	P ₁₅₀
	Total yield (t FW ha ⁻¹)		Number of heads (000 ha ⁻¹)		N _{AE} (Δ kg ha ⁻¹ DW kg ⁻¹)	
Nitrogen rate						
N ₀	12.0	10.2	68.2	66.0	–	–
N ₁₅₀	13.8	14.2	95.9	96.5	1.0	3.2
N ₃₀₀	15.2	17.5	104.3	115.3	1.0	2.8
N ₄₅₀	16.0	16.5	107.6	105.6	0.9	1.7
<i>F</i>	12.5***		3.3*		8.9***	
LSD interaction	1.0		6.7		0.5	
Season						
2003–2004	14.7	14.8	96.7	97.6	1.3	2.5
2004–2005	13.7	14.4	91.0	94.3	0.7	2.6
<i>F</i>	5.0*		15.6***		16.7***	
LSD interaction	0.6		2.9		0.4	

F Fisher–Snedecor test, *LSD* Fisher's protected least significant difference ($P \leq 0.05$)

* $P \leq 0.05$; *** $P \leq 0.001$ (significant)

significantly increase both the partial factor productivity of N (PF_{PN}) and N agronomic efficiency (N_{AE}), while the increasing N rate had a depressive effect on PF_{PN} , N_{AE} and total factor productivity (TFP; Table 2). In particular, as the N supply increased from N_{150} to N_{450} , the N_{AE} reduction was higher at P_{150} (from 3.2 to 1.7 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$) than at P_{50} (from 1.0 to 0.9 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$; Table 3); on the contrary, passing from season I to season II the N_{AE} reduction was more marked at P_{50} (from 1.3 to 0.7 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$) while no significant variation was found at P_{150} (from 2.5 to 2.6 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$; Table 3). Moreover, as the N supply increased from N_{150} to N_{450} PF_{PN} varied from 12.4 to 4.7 $\text{kg ha}^{-1}\text{ DW kg}^{-1}$ in ‘Opal F₁’ and from 7.7 to 3.1 $\text{kg ha}^{-1}\text{ DW kg}^{-1}$ in ‘Violetto di Sicilia’; similarly, within the N_0 – N_{450} range TFP decreased more markedly in ‘Opal F₁’ (from 5.4 to 2.8 $\text{kg ha}^{-1}\text{ DW kg}^{-1}$) than in ‘Violetto di Sicilia’ (from 3.0 to 1.9 $\text{kg ha}^{-1}\text{ DW kg}^{-1}$; Table 4). ‘Opal F₁’ showed, also, the highest N_{AE} increase passing from P_{50} to P_{150} (from 0.7 to 2.9 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$, +314%) as compared to ‘Violetto di Sicilia’ (from 1.2 to 2.2 $\Delta\text{kg ha}^{-1}\text{ DW kg}^{-1}$, +83%; data not shown).

Partial factor productivity is a physical parameter providing useful information about the nutrient use efficiency, as it quantifies total economic output relative to the utilization of all nutrient resources in the system (natural +external inputs; Cassman et al. 1996). Nitrogen agronomic efficiency represents the incremental efficiency of applied N as compared to unfertilized test and is proportional to the cost-benefit ratio from investment in N inputs (Novoa and Loomis 1981). We assume that, similarly to grain crops (Cassman et al. 1996; Yadav 2003; Bhattacharyya et al. 2008), it is possible to increase both partial factor productivity and agronomic efficiency (a) by increasing the uptake of indigenous nutrients and (b) by increasing the efficiency with which applied nutrients are taken up by crop and utilized to produce heads biomass. In relation to the first aspect, the adoption of the seed-propagated ‘Opal F₁’ allowed the maximization of both PF_{PN} and TFP especially at the lowest N input levels. This is attributable to a higher root dry weight recorded in this experiment in ‘Opal F₁’ in

comparison to ‘Violetto di Sicilia’ which allowed a more efficient utilization of soil resources (namely water and soil minerals), confirming previous results on differences in the root characteristics between vegetatively propagated and seed propagated cultivars (Cosentino and Mauromicale 1990; Mauromicale and Ierna 1995). In relation to the second aspect, the highest P rate showed a marked synergistic effect with N fertilization, which resulted in a more stable response to the N supply over seasons, and an improved response to the N fertilization, especially within the N_{150} – N_{300} window, where the highest N efficiency indices (namely N_{AE} and PF_{PN}) were recorded, so emphasizing the inefficiency of increasing the N dressing beyond N_{300} in non-limiting P conditions.

4 Conclusions

In the present experiment, designed to study the effects of different nitrogen and phosphorus fertilization, it emerged that the combined effect of both macronutrient rates, rather than that of nitrogen or phosphorus per se, was pivotal in determining the agronomical behavior of the crop. In particular, by increasing the phosphorus rate from 50 to 150 $\text{kg P}_2\text{O}_5\text{ha}^{-1}$, it was possible to decrease the nitrogen rate able to maximize the yield performances of the crop (from 450 to 300 kg ha^{-1}), and increasing at the same time the nutrient efficiency indices (namely partial factor productivity of nitrogen, nitrogen agronomic efficiency and total factor productivity). On the other hand, the ‘seed’-propagated hybrid ‘Opal F₁’, as compared to the vegetatively propagated ‘Violetto di Sicilia’, showed a better response to lower nitrogen supplies, especially in non-limiting phosphorus conditions, indicating its better ability to fit sustainable farming systems. Overall our data show that combining an adequate phosphorus fertilization, together with the adoption of cultivars characterized by more efficient response to nitrogen application, is a useful tool to improve the agronomic performances of the crop, ensuring, at the same time, a more environment-friendly nitrogen fertilization.

Table 4 Partial factor productivity of nitrogen (PF_{PN}) and total factor productivity (TFP) as affected by ‘genotype x nitrogen rate’ interaction

Nitrogen rate	Violetto di Sicilia PF_{PN} ($\text{kg ha}^{-1}\text{ DW kg}^{-1}$)	Opal F ₁	Violetto di Sicilia TFP ($\text{kg ha}^{-1}\text{ DW kg}^{-1}$)	Opal F ₁
N_0	–	–	3.0	5.4
N_{150}	7.7	12.4	2.6	4.2
N_{300}	4.6	7.2	2.3	3.6
N_{450}	3.1	4.7	1.9	2.8
<i>F</i>	30.2***		18.9***	
LSD interaction	0.6		0.5	

F Fisher–Snedecor test, *LSD* Fisher’s protected least significant difference ($P \leq 0.05$)
*** $P \leq 0.001$ (significant)

References

- Ashraf M, Shabaz M, Ashraf MY (2001) Influence of nitrogen supply and water stress on growth and nitrogen, phosphorus, potassium and calcium contents in pearl millet. *Biol Plantarum* 44:459–462
- Basnizki Y, Zohary D (1994) Breeding of seed planted artichoke. *Pl Breed Rev* 12:253–269
- Bhattacharyya R, Kundu S, Prakash V, Gupta HS (2008) Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean–wheat system of the Indian Himalayas. *Eur J Agron* 28:33–46
- Calabrese N, De Palma E, Bianco VV (2004) Yield and quality of new commercial seed grown artichoke hybrids. *Acta Hort* 660:77–82
- Cassman KG, Gines GC, Dizon MA, Samson MI, Alcantara JM (1996) Nitrogen-use efficiency in tropical lowland rice systems: contribution from indigenous and applied nitrogen. *Field Crop Res* 47:1–12
- Cosentino S, Mauromicale G (1990) Transpiration and plant water status of globe artichoke (*Cynara scolymus* L.) grown from seed and from vegetative organs with two water regimes. *Acta Hort* 278:261–270
- Ehaliotis C, Massas I, Pavlou G (2010) Efficient urea-N and KNO_3 -N uptake by vegetable plants using fertigation. *Agron Sustain Dev* 30:763–768
- Elia A, Conversa G (2007) Mineral nutrition aspects in artichoke growing. *Acta Hort* 630:239–249
- FAOSTAT (2008) Crops statistical database of the Food and Agriculture Organization of the United Nations. <http://faostat.fao.org/>. Assessed 18 February 2011
- Foti S, Mauromicale G, Ierna A (2005) Response of seed-grown globe artichoke to different levels of nitrogen fertilization and water supplies. *Acta Hort* 681:237–242
- Gonzalez-Dugo V, Durand JL, Gastal F (2010) Water deficit and nitrogen nutrition in of crops. A review. *Agron Sustain Dev* 30:529–544
- Khayyo S, Pérez-Lotz J, Ramos C (2004) Application of the N_{min} nitrogen fertilizer recommendation system in artichoke in the Valencian community. *Acta Hort* 660:261–266
- Magnifico V (1987) Aspetti agronomici della coltivazione del carciofo. *Inf Agr* 43:57–66
- Mauro R, Portis E, Acquadro A, Lombardo S, Mauromicale G, Lanteri S (2009) Genetic diversity of globe artichoke landraces from Sicilian small-holdings: implications for evolution and domestication of the species. *Conserv Genet* 10:431–440
- Mauromicale G, Ierna A (1995) Effects of gibberellic acid and sowing date on harvesting time and yield of seed-grown globe artichoke (*Cynara scolymus* L.). *Agronomie* 15:527–538
- Mauromicale G, Ierna A (2000) Characteristics of heads of seed-grown globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] as affected by harvest period, sowing date and gibberellic acid. *Agronomie* 20:197–204
- Mauromicale G, Ierna A, Licandro P, Maugeri R, Scandurra S (2004) Il carciofo: una coltura “nuova” per la valorizzazione delle aree irrigue della collina interna siciliana. *Italus Hortus* 11:53–59
- Novoa R, Loomis RS (1981) Nitrogen and plant production. *Plant Soil* 58:177–204
- Pandino G, Courts FL, Lombardo S, Mauromicale G, Williamson G (2010) Caffeoylquinic acids and flavonoids in the immature inflorescence of globe artichoke, wild cardoon, and cultivated cardoon. *J Agric Food Chem* 58:1026–1031
- Portis E, Mauromicale G, Barchi L, Mauro R, Lanteri S (2005) Population structure and genetic variation in autochthonous globe artichoke germplasm from Sicily Island. *Plant Sci* 168:1591–1598
- Rincón L, Pérez A, Pellicer C, Abadia A, Sáez J (2007) Nutrient uptake by artichoke. *Acta Hort* 730:287–292
- Ryan J (1998) Changes in organic carbon in long-term rotation and tillage trials in Northern Syria. In: Lal R, Kimble JM, Follett RF, Stewart BA (eds) Management of carbon sequestration in soil. *Advances in Soil Science* CRC Publisher, Boca Raton, pp 285–295
- Ryan J, Masri S, Ceccarelli S, Grando S, Ibricci H (2008) Differential responses of barley landraces and improved barley cultivars to nitrogen–phosphorus fertilizer. *J Plant Nutr* 31:381–393
- Società Italiana Scienza del Suolo (1985) Metodi normalizzati di analisi del suolo. Edagricole, Bologna, p 100
- Spiertz JHJ (2010) Nitrogen, sustainable agriculture and food security. A review. *Agron Sustain Dev* 30:43–55
- White PJ, Brown PH (2010) Plant nutrition for sustainable development and global health. *Ann Bot* 105:1073–1080
- Yadav RL (2003) Assessing on-farm efficiency and economics of fertilizer N, P and K in rice wheat systems of India. *Field Crop Res* 81:39–51
- Zubillaga MM, Aristi JP, Lavado RS (2002) Effect of phosphorus and nitrogen fertilization on sunflower (*Helianthus annuus* L.) nitrogen uptake and yield. *J Agron Crop Sci* 188:267–274