Effect of Fertilization on Yield and Quality of Biomass of Quinoa (*Chenopodium quinoa* Willd.) and Green Amaranth (*Amaranthus retroflexus* L.)

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Abstract

The effect of organic and inorganic fertilization on yield and biomass quality of two species: quinoa (*Chenopodium quinoa* Willd.) and green amaranth (*Amaranthus retroflexus* L.) was studied in this paper. The agronomic performance and nutritional value of quinoa and green amaranth was analyzed in order to establish them as alternatives to local forages for dry-season feeding of ruminants in the Mediterranean region. The experiment was laid out in a split-plot design with two replicates, two main plots (quinoa and amaranth) and four sub-plots (fertilization treatments: control, inorganic fertilization, compost and cow manure). The results indicated a clear superiority of quinoa over the amaranth in height and dry matter, while there were no differences in the nutritional value of biomass between the two species. In general, fertilization had a positive impact on growth and yield of both species. Fertilization with compost showed higher values in most quality traits of biomass in the quinoa crop, while inorganic fertilization had better results in amaranth. The results of this study suggest that quinoa and green amaranth crops could be used as an alternative feed over spring legumes in dry-warm Mediterranean areas.

Keywords: *Amaranthus retroflexus*, biomass quality, *Chenopodium quinoa*, fertilization, yield

INTRODUCTION

Quinoa and amaranth belong to the group of crops known as pseudocereals that includes other domesticated chenopods, amaranths and buckwheat. Quinoa (*Chenopodium quinoa* Willd.), is a stress-tolerant plant, cultivated along the Andes, from about 3000 B.C. It is still cultivated in Peru, Bolivia, Chile, Ecuador, Colombia and Argentina (Gonzalez *et al.*, 2012). Its grains have a high-protein content with abundance of essential amino acids, and a wide range of vitamins, minerals and saponin and it is a promising worldwide plant for human consumption and nutrition (Bilalis *et al.*,

2012; Vega-Gálvez *et al.*, 2010). The Organization of the United Nations for Food and Agriculture (FAO) has declared the year 2013 as the year of the quinoa (FAO, 2013).

The genus *Amaranthus* includes about 60 species, most of which are cosmopolitan weeds associated with difficulties in cultivation practices after soil disturbance and seed exposure to light. The three principal species of genus *Amaranthus*, originating in South America are *A. hypochondriacus* L., *A. cruentus* L. and *A. caudatus* L., cultivated for their seeds which used as cereals and their edible leaves (Bressani, 2003). In Greece

green amaranth (*Amaranthus retroflexus* L.) is a native plant appreciated in young stage for his edible leaves.

The number of studies on fertilization requirements of pseudocereals is still quite limited. For amaranth it was shown that N fertilization enhanced grain yield in many environments (Elbehri *et al.*, 1993). The grain yield of quinoa was significantly increased by increasing N fertilization from 40 to 160 kg ha⁻¹, the yield response, however, was only moderate (Jacobsen *et al.*, 1994). Moreover, limited data are available regarding the fodder quality of quinoa and green amaranth crops. Bhargava *et al.* (2010) reported that the foliage of many species of *Chenopodium* (*C. album*, *C. berlandieri*, *C. bushianum*, *C. giganteum*, *C. murale*, *C. quinoa*, and *C. ugandae*) is a rich source of minerals like potassium, sodium, calcium and iron. The foliage of quinoa is rich in protein, carotenoid and ascorbic acid. Therefore, members of the genus *Chenopodium* are used as a foliage crop and fodder in many parts of the world (Bhargava *et al.*, 2010).

In temperate regions, white clover (*Trifolium repens* L.) is the predominant species used for grazing, whereas red clover (*Trifolium pratense* L.) and alfalfa (*Medicago sativa* L.) are cultivated mainly for hay and silage making (Krawutschke *et al.*, 2013, Papanastasis and Mansat, 1996). Drought is an adverse factor that forages must cope with in the Mediterranean region. Quinoa is able to tolerate drought and can grow with only 200 mm of rainfall. (Jacobsen, 2003; Razzaghi *et al.*, 2012).

Therefore, the aim of this study was to determine the effects of different fertilization treatments on yield and biomass quality of quinoa and green amaranth under Mediterranean semi-arid conditions.

MATERIALS AND METHODS

The research has been carried out at the Agricultural University organic farm located in Athens (southern Greece: latitude 37°58' N, longitude 23°32' E, altitude 30 m above sea level) from Mars to July 2013. The soil was clay loam (29.8 % clay, 34.3 % silt and 35.9 % sand) with pH 7.29, NO₃-N 12.4 mg kg⁻¹ soil, available P 13.2 mg kg⁻¹ soil, available K 201 mg kg⁻¹ soil and 1.47 % organic matter. The site was managed according to organic agriculture guidelines (EC

834/2007). The experiment was laid out in a split-plot design with two replicates, two main plots (quinoa and green amaranth) and four sub-plots [fertilization treatments: control, inorganic fertilization (fertilizer 26-0-0 with 100 kg N ha⁻¹), seaweed compost (2000 kg ha⁻¹ Posidonia 1-2% N, CompostHellas) and cow manure (2000 kg ha⁻¹, 1.24% N)]. The main plot size was 90 m² and the sub-plot 20 m² with wheat (*Triticum turgidum* subsp. *durum* L.) as preceding crop. Quinoa and green amaranth were sown on 23th of Mars 2013 by hand in rows 30 cm apart at a depth of 2-3 cm at a rate of 10 kg ha⁻¹. Overhead sprinkler system was set up on the field. The total quantity of water was 180 mm. Finally, weeds were controlled by hand hoeing when necessary.

For the computation of fresh and dry weight, height and LAI (110 DAS), 10 plants were randomly selected in each plot. The dry weight was determined after drying for 72 h at 70°C. Leaf area was measured using an automatic leaf area meter (Delta-T Devices Ltd). Thus, the measurements of plant basis were converted into a LAI by multiplying by the average crop density of each plot. In each subplot 10 plants were collected (110 DAS) and oven-dried to constant weight at 70°C. The samples were ground to fine powder and used for determinations of total ash content, crude fat (Soxhlet extractor), total nitrogen content and acid detergent fibre. The total nitrogen was determined by the Kjeldahl method. Moreover, total protein content was calculated from the nitrogen content using a conversion factor of 6.25 (AOAC, 2009). Acid detergent fibre (ADF) was determined according to the methods of Van Soest *et al.* (1991).

Weather data (air temperature and rainfall) were recorded daily and are reported as mean monthly data for the cultivation period (Table 1). The spring was quite mild and had lower rainfall compared to the 35-year average.

The data were subjected to statistical analysis according to the split-plot design. The statistical analysis was performed with STATGRAPHICS Plus 5.1 logistic package. Differences between treatment means were compared at P=5% with ANOVA in order to find the statistically significant differences.

Tab. 1. Monthly means of air temperature and rainfall during Mars to July 2013 and the 35-year average (1979-2013) at Athens, Greece.

Months	Temperature (°C)		Rainfall (mm)	
	2013	35-years average	2013	35-years average
March	14,4	12,3	14,6	43,1
April	18,4	16,0	2,6	30,7
May	23,4	20,8	6,2	17,0
June	26,0	25,6	12,0	7,8
July	28,6	28,2	0	6,6

Tab. 2. Effects of plant species (quinoa and green amaranth) and fertilization (control, inorganic N fertilization, compost, cow manure) on height (cm), leaf area index (LAI), dry and fresh biomass weight (kg ha⁻¹).

Species	Fertilization	Height (cm)		LAI	Dry biomass weight (kg ha ⁻¹)		Fresh biomass weight (kg ha ⁻¹)	
Quinoa	Control	150,5	Ac	2,87	5500		45250	
	Inorganic N	175,0	Aa	3,26	5900		53750	
	Compost	163,0	Ab	3,12	8430		77500	
	Manure	169,0	Aab	2,94	7390		77000	
	Average	164,4	A	3,05	6800		63380	
Amaranth	Control	90,0	Ba	2,72	5250		42500	
	Inorganic N	92,0	Ba	3,43	5500		45750	
	Compost	95,0	Ba	3,48	6750		71000	
	Manure	93,0	Ba	3,21	6500		63380	
	Average	92,5	B	3,21	6000		55660	
Average	Control	120,3	c	2,80	5380	a	43880	a
	Inorganic N	133,5	a	3,34	5700	a	49750	a
	Compost	129,0	b	3,30	7590	b	74250	b
	Manure	131,0	ab	3,07	6950	ab	70190	b
	Species	**		ns	ns		ns	
	Fertilization	***		ns	*		*	
	Species × Fertilization	***		ns	ns		ns	

ns, not significant; significant at * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

RESULTS AND DISCUSSION

The analysis of variance of our data revealed significant differentiation of plant height between the two species, the lowest values were found in green amaranth (Table 2). Fertilization had a positive effect on plant height compared with the control. In particular, inorganic N fertilization and cow manure showed higher values in quinoa crop, while there were no significant differences between the fertilization treatments in green amaranth.

Different lower-case letters within a column indicate significant differences between fertilization mean values ($P<0.05$). Different upper-case letters within a column indicate significant differences between the mean values of different species ($P<0.05$).

Leaf area index (LAI) showed small differences between the plant species and was not influenced by the fertilization treatments. Although no statistically significant differences were observed, the green amaranth responds

better to fertilization than quinoa. Similar results concerning the positive response of the quinoa crop to inorganic N fertilization reported by other researchers (Schooten and van Pinxterhuis, 2003; Schulte auf'm Erley *et al.*, 2005). Moreover, Bilalis *et al.* (2012) and Kakabouki *et al.* (2014) did not observed differences in leaf area index between the fertilization treatments in quinoa crop. The lower yield values in fresh and dry weight were occurred for both plant species without fertilization, while the compost and cow manure treatments showed higher yield values (Table 2). Data from other studies showed the positive impact of the organic fertilization on dry matter yield in quinoa reaching 8650 kg ha⁻¹ and 8800 kg ha⁻¹ for compost and cow manure, respectively (Bilalis *et al.* 2012).

Significant interaction ($P>0.01$) among the studied factors (i.e. plant species and fertilization treatments) were observed for the biomass qualitative characteristics, specifically in total ash, acid detergent fibre (ADF) and crude fat, while there are not significant differences between the fertilization treatments for total ash and crude

protein content (Table 3). Forage species differ in their crude protein content. Dugalić *et al.* (2012) reported that crude protein content in alfalfa plants ranged between 21.7% - 25.9% and Kakabouki *et al.* (2014) observed higher values of crude protein in quinoa plants treated with inorganic N fertilization (23%) compared with cow manure (21%). Forage intake is affected by crude protein, fibre and ash content (Ibrahim *et al.*, 2012). Acid detergent fibre is a major indicator of digestibility, negatively affects feed quality (Han *et al.*, 2003). In quinoa, the fertilization treatment with compost revealed higher values of crude protein, total ash, crude fat and lower values of acid detergent fibre compared with the other fertilization treatments, while inorganic N fertilization showed better results in green amaranth crop.

Different lower-case letters within a column indicate significant differences between fertilization mean values ($P<0.05$). Different upper-case letters within a column indicate significant differences between the mean values of different species ($P<0.05$).

Tab. 3. Effects of plant species (quinoa and green amaranth) and fertilization (control, inorganic N fertilization, compost, cow manure) on total ash, acid detergent fibre, crude fat and crude protein content as % of the sample dry weight.

Species	Fertilization	Total ash		Acid detergent fibre		Crude fat		Crude protein
Quinoa	Control	18,2	Aa	28,4	Aa	2,50	Aa	12,5
	Inorganic N	18,0	Aa	32,1	Aa	2,20	Aa	11,1
	Compost	18,8	Aa	30,8	Aa	2,87	Aa	14,7
	Manure	18,7	Aa	27,1	Aa	2,16	Aa	13,0
Average		18,4	A	29,6	A	2,43	A	12,8
Amaranth	Control	22,0	Ba	26,2	Aa	1,72	Ba	10,8
	Inorganic N	22,3	Ba	26,5	Ba	1,64	Ba	8,4
	Compost	19,2	Aa	23,4	Ba	1,29	Ba	9,1
	Manure	21,1	Ba	20,4	Ba	1,60	Ba	8,8
Average		21,2	B	24,1	A	1,56	A	9,3
Average	Control	20,1	a	27,3	a	2,11	a	11,6
	Inorganic N	20,2	a	29,3	a	1,92	ab	9,7
	Compost	19,0	a	27,1	a	2,08	a	11,9
	Manure	19,9	a	23,8	b	1,88	b	10,9
Species		ns		ns		ns		ns
Fertilization		ns		*		*		ns
Species × Fertilization		**		**		**		ns

ns, not significant; significant at * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

CONCLUSION

The results indicated a clear superiority of quinoa over the amaranth in height and dry matter, while there were no differences in the nutritional value of biomass between the two species. In general, fertilization had a positive impact on growth and yield of both pseudocereals. Fertilization with compost showed higher values in most quality traits of biomass in the quinoa crop, while inorganic fertilization had better results in amaranth. The results of this study suggest that the quinoa and amaranth crops could be used as an alternative feed over spring legumes in dry-warm Mediterranean areas.

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