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YIELD RESPONSE OF QUINOA TO FERTILIZATION AND IRRIGATION

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Abstract

Quinoa (Chenopodium quinoa Willd.) is a pseudograin with its origin from the Andes in South America. The aim of this research was to investigate the effect of fertilization as well as irrigation on yield mass of quinoa, quinoa yield components and morphological properties, as well as the chemical composition of quinoa leaves. The highest value of aboveground yield has been achieved on treatment N1+M (17.01 t ha⁻¹) and the least one in the control (12.41 t ha⁻¹). Considering all the observed characteristics, on average, the highest values were recorded in N2, then in N1+M treatment, while the lowest values were represented on the control treatment.

Key words: quinoa, fertilization, yield, microbial fertilizers

1. INTRODUCTION

Quinoa (*Chenopodium quinoa Willd.*) is a pseudograin with its origin from the Andes in South America (Bazile et al., 2013). This plant species is called "vegetable caviar" or "rice of the Incas" and the people residing those mountainous highlands and valleys, where 90% of the total world production is concentrated, uses quinoa as food more than 5000 years. In Europe, quinoa was first tested and adapted in Denmark (Jacobsen, 1997) after which experimental production began in Finland and the UK (Abugoch, 2009). Quinoa is a very interesting culture because of its nutritional properties. The nutrient value of quinoa lies in the presence of protein (all essential amino acids), trace elements, vitamins, linoleic acid (omega-3) and amylase, and it does not contain gluten (Demin et al., 2012; Bazile et al., 2013). The quinoa seeds contains carbohydrates (57.7% of dry matter) and high quality proteins (15.8% of dry matter) (FAO, 2011). The grains are source of a significant amount of cellulose fibers (4.1% of dry matter) that positively influence the digestive organs. However, seed pericarp contain saponins (0.1 to 5%) that give a bitter taste in aqueous solutions and causes foaming (Jancurova et al., 2009). Quinoa leaves are used as food since pre-Colombian times (Bhargava et al., 2008) and are suitable for preparing various cooked dishes (Galwey, 1989; Jevdović et al., 2012). The fibers make up 1.9% of the fresh leaf mass and 6% of the dry mass of the seed, therefore quinoa input encourages better digestion, regulates cholesterol, stimulate the development of beneficial bacterial flora and helps prevent colon cancer (FAO, 2011).

Nowadays, it has become necessary to search for new, alternative fertilizers as substitutes for chemical ones. According to Avila and Etchevers (1988), quinoa should be properly fertilized with nitrogen, phosphorus and potassium in order to ensure acceptable yield of seeds (about 3000 kg ha⁻¹), where N fertilizer has the greatest importance. Remarkable effects of untraditional fertilizers, especially biofertilizers have been reported on the plant growth and yield (Hajnal Jafari et al., 2012; Stamenov et al., 2012; Vasic et al., 2014). Research shows that quinoa in Serbia can be successfully grown in Vojvodina, in river valleys to mountainous areas and over 1500 m above the sea level (Jevdović i sar., 2012).

Due to the increasing demand and interest towards this plant, the need for more comprehensive research in quinoa production emerged in Serbia. In this work, the effect of different doses and types of fertilizer as well as irrigation on quinoa yield mass, quinoa yield components as well as the chemical composition of quinoa leaves were investigated.

2. MATERIAL AND METHODS

2.1. Field trial

Field trials were set up on chernozem soil type during 2013. Two factorial study was set up where quinoa was sown (variety KVL - 37, University for Life Science, Copenhagen, Denmark) at two main plots, one of which was irrigated. Different fertilization treatments were applied on both plots with four replications in a randomized complete block design. Basic plot area was 9 m².

Fertilization treatments were arranged as shown: Ø – control; N₁ – 85 kg ha⁻¹ („Siforga”); N₂ – 170 kg ha⁻¹ („Siforga”); N₁+M - 85 kg ha⁻¹ + „BactoFil B - 10”; M - „BactoFil B - 10”.

„Siforga” is a organic fertilizer (N:P:K 5:3:8). It also contains magnesia (MgO 0,8%), calcium (CaO 9,1%), and high percentage of organic matter (65%). „BactoFil B - 10” (“A&S UNION” D.O.O. Subotica, Serbia) is as a microbial fertilizer and contains several PGP bacteria (*Azotobacter vinelandii*; *Azospirillum lipoferum*; *Bacillus megaterium*; *Bacillus subtilis*; *Bacillus circulans*; *Pseudomonas fluorescens*).

Continuous sowing of quinoa was performed on 19th April 2013. With a single-hand seeder for small seeds. The inter-row distance was 50 cm and the sowing density of 6 kg ha⁻¹ was applied. Since higher amount of seed was used, crop thinning was carried out after forming the first true leaves.

Fertilization treatments were irrigated in the last decade of April (no rain, and the total rainfall for April was significantly lower than the long-term average, total 30mm). Irrigation was performed through irrigation system. The system was connected to the stationary pump (16 l s⁻¹ capacity).

2.2. Laboratory analyses

Laboratory analysis of plant material were conducted in the laboratory for agricultural chemistry at the Faculty of Agriculture in Novi Sad.

The following properties of plant material were analyzed: yield of aboveground parts of quinoa plants (t ha⁻¹), yield components of quinoa-plant mass (g), fresh and dry leaves mass (g), chemical composition of quinoa leaves-nitrate content (mg kg⁻¹), protein content (%), total nitrogen content (%), content of iron (mg kg⁻¹), zinc (mg kg⁻¹) and of manganese (mg kg⁻¹).

Dry matter was determined by drying the leaves samples in an oven at 60 ° C until constant mass. The nitrate concentration in the leaves after extraction with distilled water and application of phenol-di-sulfonic acid and ammonium hydroxide was determined by spectrophotometry (λ 420) (Arsenijevic-Maksimovic and Pajević, 2002). Determination of total N in the leaves was performed by the method of Kjeldahl. Determination of total protein in the leaves was performed by calculating the amounts of nitrogen in the amount of protein. Nitrogen content of seeds was multiplied by 6.25 to calculate the crude protein content (Anon., 1990). Laboratory determination of trace elements (Fe, Mn and Zn) were performed by atomic absorption spectrophotometry (AAS).

2.3. Statistical analyses

For calculating analysis of variance and comparisons of means, Statistica 10 software (Hamburg, Germany) was used. The *LSD* test was used to detect and separate the mean treatment differences. Correlation analyses were used to describe the relationships between growth parameters and yield components. All comparisons were made at the 5% level of significance.

3. RESULTS AND DISCUSSION

Between fertilization treatments that were not irrigated no statistical significance was achieved (Table 1). At fertilization treatments that were irrigated, highest average yields of aboveground mass was achieved in treatments N1 and N2 + M. Those increases in yield were significantly different than the yield achieved in the control and treatment N1.

Table 1. Yield of above ground parts of quinoa plants (t/ha)

Fertilization treatments	No irrigation	With irrigation
Control	7,31a	17,52b
N1	8,20a	17,17b
N2	9,81a	23,63a
N1+M	9,87a	24,13a
M	8,57a	19,17ab

Ø - control; N1 - 85 kg ha⁻¹ N; N2 - 170 kg ha⁻¹ N; N1+M - 85 kg ha⁻¹ N + Bactofil; M - Bactofil

* Mean values with the same superscript(s) are not significantly different at 5% (p<0,05)

Examining the effect of different doses of fertilization on the above-ground parts yield of quinoa, Meyers (1998) and Sharms (2012) found that the yield biomass increased with the increased doses of nitrogen. Bogdanovic et al. (2008) also noted that the variants with microbiological fertilizer in combination with 50% of the dose of nitrogen gave the highest grain yield and yield of wheat straw as compared to other treatments with various fertilization patterns.

Significantly higher yield biomass achieved in N1 + M treatment can be attributed to the fact that the *Azotobacter* sp., a free living nitrogen fixing bacteria in our conditions fixed around 60 - 90 kg N ha⁻¹ year and therefore can be applied in crop production as a replacement for a part of mineral nitrogen fertilizers (Govedarica et al., 2004; Hajnal et al., 2004). Furthermore, bacteria produce different biologically active substances such are hormones, vitamins, amino acids that could positively influence the initial plant growth and development resulting in increased biomass and yield.

Table 2. Plant mass, fresh and dry leaves mass (g)

Fertilization treatments	Plant mass		Fresh leaves mass		Dry leaves mass	
	No irrigation	With irrigation	No irrigation	With irrigation	No irrigation	With irrigation
Control	24,38a	58,39b	12,52a	30,19bc	1,51a	2,68b
N1	27,21a	57,23b	13,47a	27,59c	1,54a	2,60b
N2	32,72a	78,78ab	17,00a	38,96ab	1,88a	3,43a
N1+M	32,92a	80,49a	17,67a	39,93a	1,98a	3,08ab
M	28,60a	63,39ab	14,83a	32,01abc	1,69a	2,72b

Ø - control; N1 - 85 kg ha⁻¹ N; N2 - 170 kg ha⁻¹ N; N1+M - 85 kg ha⁻¹ N + Bactofil; M – Bactofil

* Mean values with the same superscript(s) are not significantly different at 5% (p<0,05)

Analysis of the whole plant mass was carried out at the stage of intensive growth (before flowering), when the plants were at the stage of technological maturity. At fertilization treatments that were under irrigation, the highest average mass of the plants was recorded in treatment N1 + M (32.92 g) and N2 (32.72 g), while the lowest average mass of the plants was determined in the control treatment - Ø (24,38 g). However, analysis of variance showed no statistically significant differences among the treatments (Table 2). Under irrigation treatments, the highest value of the average mass of the plants was observed in N1 + M treatment (80.49 g) which was significantly higher than the mass of the plant

accomplished in N1 (40.6%) and the control treatment - Ø (38%), while not significantly different compared to treatments N2 and M (Table 2).

The highest mass, which was achieved on N1 + M, can be explained by the fact that the application of microorganisms increased the accessibility of nutrients which reflects positively on the parameters of yield (Milošević, 2003). There are many evidence that beneficial microorganisms enhance plant growth and could be an effective alternative to mineral fertilizers in crop production. The bioproducts composed of *Bacillus subtilis* strain BAQ-11, *Trichoderma koningiopsis* and *Trichoderma harzianum* were tested in field conditions in Altiplano region, resulting in increased quinoa yield compared to the control without microorganism amendment (Ortuno et al., 2013). Mahfouz and Sharaf-Eldin (2007) mentioned that the highest yield per plant of wheat was observed with the treatment of biofertilizer (mixture of *Azotobacter chroococcum*, *Azospirillum lipoferum*, and *Bacillus megatherium*) plus a half dose of chemical fertilizers (only 50% of nitrogen and phosphorus).

Gomaa (2013) observed that application of 100 and 150 kg ammonium nitrate / fed. combined with nitrobin (microbial fertilizer) gave the maximum significant effect in plant height, number of branches, number of leaves, number of inflorescence and dry weight / plant. Nitrogen and phosphorus fertilizers in combination with biofertilizers (nitrobin and phosphorin) increased the average weight of 1000 seeds but levels of 0 or 150 Kg ammonium nitrate and calcium super phosphate /fed. with biofertilizers showed no significant effect. In order to fully examine the influence of fertilization and irrigation on the growth of quinoa, in addition to the total mass of the plant, fresh leaf mass and the leaf dry matter production were measured as well. At fertilization treatments whit no irrigation, the maximum value of the fresh leaf mass (FLM) was achieved in treatment N1 + M (17.67 g) while the lowest value was in the control treatment Ø (12.52 g). However, analysis of variance showed no significant differences in fresh leaf mass between the tested treatments (Table 2). Furthermore, dry leaf mass (DLM) showed no statistically significant difference between fertilization treatments that were not irrigated (Table 2). The highest value FLM, with irrigated treatment was observed in the treatment N1 + M (39.93 g).

Table 3. Nitrate content in fresh leaves mass, proteine content in dry leaves mass, nitrogen content in dry leaves mass (%)

Fertilization treatments	Nitrate content		Proteine content		Nitrogen content	
	No irrigation	With irrigation	No irrigation	With irrigation	No irrigation	With irrigation
Control	972ab	1111a	23,59b	22.64a	3,78b	3.62a
N1	1239ab	1134a	25,23ab	23.37a	4,04ab	3.74a
N2	1934a	1688a	27,11a	23.41a	4,34a	3.74a
N1+M	815b	1044a	24,76b	21.80a	3,96b	3.49a
M	863b	1112a	24,59b	22.78a	3,94b	3.64a

Ø - control; N1 - 85 kg ha⁻¹ N; N2 - 170 kg ha⁻¹ N; N1+M - 85 kg ha⁻¹ N + Bactofil; M - Bactofil

* Mean values with the same superscript(s) are not significantly different at 5% (p<0,05)

The highest nitrate content in fresh leaf mass, in fertilization treatments that were not irrigated was recorded in the treatment N2, and varies considerably in relation to the nitrate content recorded in treatments N1 + M and M. Analysis of variance showed no statistically significant differences in the content of nitrate in fresh leaf mass between fertilization treatments that were under irrigation (Table 3).

Cabilovski (2009) found that the nitrate content in lettuce was significantly affected by fertilization. The same allegations were stated by Bošković-Rakočević et al. (2010). Authors discovered that the nitrate content on spinach increased with the increased doses of applied nitrogen. El Youssfi et al. (2013) found that the nitrate content in the soil decreased in the period of growing quinoa, therefore, conclude that quinoa is one of the those plants that significantly accumulate nitrates. Nitrate content in fresh leaf mass in all tested treatments is shown in Table 3. It can be seen that the nitrate content did not exceed the maximum permissible content of nitrate in spinach and lettuce (2500 mg kg⁻¹) as prescribed by the European Union (Council Regulation (EC) No 834/2007). De Bruin (1964) and White *et al.* (1978) found that protein percentages in quinoa plant were increased by phosphorus supply, quinoa had a high content of calcium, phosphorus, and iron and was low in sodium. David *et al.* (1998) pointed that nitrogen applications significantly increased protein content of quinoa. The authors found that protein percentage increased by 0.1% per kg of ammonium nitrate applied and that nitrogen applications have significantly increased protein content of quinoa. Berti *et al.* (2000) mentioned that protein yield was linearly correlated to nitrogen application.

The highest protein content in the treatment without irrigation was recorded in treatment N2 (27.11%). The highest protein content among treatments under irrigation, was recorded also in treatment of N2, while the lowest in N1 + M treatment. However, no statistically significant differences among the treatments were recorded (Table 3).

At fertilization treatments that were not irrigated, highest nitrogen content was achieved in treatment N2 (4.34%). Treatments N1, N1 + M, M and control - Ø did not differ significantly. On irrigated fertilization treatments no significant differences were established regarding the nitrogen content (Table 3).

Table 4. Content of Fe, Zn and Mn in dry leaves mass

Fertilization treatments	Fe content		Zn content		Mn content	
	No irrigation	With irrigation	No irrigation	With irrigation	No irrigation	With irrigation
Control	501,41a	470.22ab	14.20ab	17,32b	46.44a	40.44a
N1	438.51ab	520,66a	14,96a	17.48ab	37.90a	40.66a
N2	381,37b	386.96ab	14,75a	16,98b	38.60a	35.09a
N1+M	392,33b	254,13b	14.24ab	18.85a	44.80a	34.88a
M	416.46ab	363.69ab	13,20b	17.40ab	44.05a	38.47a

Ø - control; N1 - 85 kg ha⁻¹ N; N2 - 170 kg ha⁻¹ N; N1+M - 85 kg ha⁻¹ N + Bactofil; M - Bactofil

* Mean values with the same superscript(s) are not significantly different at 5% (p<0,05)

The highest content of iron (Fe) in dry leaf mass in treatment without irrigation was recorded in control which differed significantly (at 5%) from the content in treatments N2 and N1 + M. The only significantly higher Fe content in the dry leaf mass was recorded in treatment N1 in relation to the N1 + M treatment (Table 4).

The content of zinc (Zn) in the treatment without irrigation was highest in treatments N1 (14.96 mg kg⁻¹) and N2 (14.75 mg kg⁻¹) and was significantly higher (p <0.05) compared to the M treatment (13.20 mg kg⁻¹). In the treatments under irrigation significantly higher content of Zn in leaf dry mass was recorded in N1 + M treatment in relation to treatment N2 (16.98 mg kg⁻¹) and control - Ø (17.32 mg kg⁻¹) (Table 4). Tested fertilization treatments did not differed significantly in the content of manganese (Mn) regardless of irrigation (Table 4).

The lowest content of Fe in the leaf dry mass was achieved in treatments N1 + M, where the organic fertilizer "Siforga" together with "BactoFil" containing microorganisms *Bacillus megatherium* and *Pseudomonas fluorescens* were applied. Those bacteria enhance the accessibility of phosphate and improve its intake by plant. However, it could lead to decrease in the concentration of Fe in the plant (Adams, 1980; Milivojević et al., 2005).

From these results, it can be concluded that the growth characters, plant yield and leaf quality of quinoa plant can be improved by the application of some effective measures such as irrigation, use of organic fertilizers and/or biofertilizers. In the climatic conditions in Vojvodina/Serbia, irrigation has an additional character (Pejić et al., 2011). It is used in order to increase and stabilize the yield of cultivated plants. Organic fertilizers are used in organic production as a source of essential nutrients for plants, but also because of many beneficial effects on physical and chemical properties of soil. Using effective microorganisms, a significant reduction in mineral fertilizers application could be achieved and at the same time avoid harmful effect on the environment. This research gave a valuable contribution to the organic production of quinoa, especially to small farmers to whom quinoa may be an interesting new agricultural crop.

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