Seed and Saponin Production of Organic Quinoa (Chenopodium quinoa Willd.) for different Tillage and Fertilization

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Abstract

Field experiment was conducted to determine the effects of tillage systems and fertilization on growth, yield and quality of quinoa crop (Chenopodium quinoa Willd.). The experiment was laid out in a split-plot design with four replicates, two main plots [conventional tillage (CT) and minimum tillage (MT)] and three sub-plots (fertilization treatments: control, cow manure and compost). The soil porosity (45.5-49.75%) and total nitrogen (0.144-0.173%) were higher in soils subjected to MT system than under CT. In soil porosity, an interaction between fertilization and tillage system was found. The highest leaf area index (4.47-5.03), dry weight (8650-9290 kg ha⁻¹) and root density (1.03-1.21 cm cm⁻³) were also found in MT. Moreover, there were significant differences between the organic fertilization treatments concerning the LAI, dry weight and root density. The highest seed yield (2485-2643 kg ha⁻¹) and saponin content (0.42-0.45%) were found in cow manure and compost treatments. Also, the highest saponin yield (7.70-12.05 kg ha⁻¹) was found in the MT system. Saponin yield had positive and significant correlation with total N (r=0.866, p<0.001). In quinoa measurements, an interaction between fertilization and tillage system was not found. The present results indicated that MT and organic fertilization increase saponin yield of quinoa.

Keywords: fertilization, quinoa, no-tillage, organic, saponin, tillage system

Introduction

Quinoa (Chenopodium quinoa Willd.) is a pseudocereal that has been cultivated in Andean region for thousands of years (Bhargava et al., 2006). Quinoa has been called a pseudo-cereal for botanical reasons but also, because of its unusual composition and exceptional balance between oil, protein and fat. Quinoa is an excellent example of ‘functional food’ that aims at lowering the risk of various diseases (Vega-Gálvez et al., 2010). It has remarkable nutritional properties; not only its protein content (15%) but also its great amino acid balance. It is an important source of minerals and vitamins, and it has been found to contain compounds like polyphenols, phytosterols, and flavonoids with possible nutraceutical benefits (Abugoch James, 2009). Moreover, quinoa plants contain saponins (Kuljanabhagavad and Wink, 2009). Saponins in quinoa are basically glycosidic triterpenoids with glucose constitution about 80% of the weight (Bhargava et al., 2006).

Quinoa has a significant, worldwide potential as a new cultivated crop species and as an imported commodity from South America (Jacobsen, 2003). Little information is currently available on quinoa crop production. Schulte auf ‘m Erley et al. (2005) reported that quinoa responded strongly to nitrogen fertilization, Berti et al. (2000) also found that the highest quinoa yields were obtained with the highest nitrogen rate (225 kg ha⁻¹). Moreover, Eisa et al. (2012) reported that quinoa is a promising salt-tolerant plant and it can be grown productively under low to moderate saline conditions.

Tillage systems affect soil physical properties differently, because of their varied tillage intensities, which in turn affect infiltration characteristics (Bhattacharyya et al., 2008). Under minimum tillage (reduced tillage) agriculture, the soil is not inverted and mixed with the crop residues and this seems to profoundly impact many soil properties particularly in the upper soil layer (D’Haene et al., 2008). Daraghmeh et al. (2009) reported that reduced tillage improved soil structure through a combination of increased soil organic matter, reduced soil bulk density and increased proportion of larger aggregates. Alvarez and Steinbach (2009) also observed that aggregate stability and water infiltration rate were higher in soils subjected to limited tillage systems than under plow tillage.

Data obtained by other researchers (Bhattacharyya et al., 2008; Bilalis et al., 2010; Cantero-Martinez et al., 2007; Elhimiadou et al., 2009; Quattara et al., 2008) clearly demonstrate the beneficial effects of reduced till-
age and organic fertilization on the yields of crops (flax, maize, cotton). **There were no information about the effects of tillage systems and organic fertilization on quinoa growth and yield.** Therefore, the aim of this study was to determine the effects of tillage system and organic fertilization on growth and saponin content yield of quinoa crop. Limited data are available regarding the performance of quinoa growth in an organic cropping system.

**Material and methods**

**Experimental design**

A quinoa crop (*Chenopodium quinoa* Willd.) was established in the area of Agrinio (western Greece, Lat: 38°35', Long: 21°25') in 2010 and 2011. The soil was a clay loam (24.9% clay, 61.2% silt, and 13.9% sand) with pH 7.4, organic matter 1.45%, EC 0.63 mS cm⁻¹, 0.152% total nitrogen and a sufficient supply of phosphorus (P Olsen: 175 mg kg⁻¹ soil) and potassium (652 mg kg⁻¹ soil). Some meteorological data of the experimental sites are presented in Fig. 1. The sites were managed according to organic agriculture guidelines (EC 834/2007). The experiments were set up on an area of 600 m² according to the split-plot design with four replicates, two main plots (conventional tillage: CT, moldboard plowing at 20-25 cm, followed by one rotary hoeing at 5-10 cm; minimum tillage: MT, chiseling at 20 cm depth followed by one rotary hoeing at 5-10 cm; no-tillage) and three sub-plots (fertilization treatments: control, cow manure (2000 kg ha⁻¹, 1.24% N) and seaweed compost (250 kg ha⁻¹, with 8% N). The main plot size was 150 m². The crop was cultivated before quinoa becomes wheat. Quinoa was sown by hand in rows 30 cm apart, at a depth of 3 cm. Quinoa was sown on 10th of May 2010 and 15th of May 2011 at a rate of 10 kg ha⁻¹. Finally, weeds were controlled by hand 30 days after sowing.

**Sampling, measurements and methods**

Total porosity of the soil was determined by 1-Db/Dp, where Dp is the particle density (2.5 g cm⁻³) and Db is the soil bulk density. Soil bulk density was determined for each plot by taking undisturbed soil cores with 100 cm³ cylinders from a depth of 0-10 cm. Three samples of 100 cm³ per plot were taken (90 days after sowing (DAS). The undisturbed samples were finally oven dried at 100°C for 24 h to obtain soil dry mass and the soil bulk density was calculated as follow: Db=dry mass (g)/100 cm³. The total nitrogen was determined by the Kjeldahl method (Bremner, 1960) using a Buchi 316 device in order to combust and extract the soil samples.

For the computation of dry weight and LAI (75 DAS), 10 plants were randomly selected in each plot. The dry weight was determined after drying for 72 h at 70ºC. Leaf area was measured using an automatic leaf area meter (Delta-T Devices Ltd). Root samples were collected 75 DAS and from the 0-25 cm layer by using a cylindrical auger (25 cm length, 10 cm diameter) at the midpoint between successive plants within a row. For each sample, roots were separated from soil after being in water + (NaPO₃)₆ + Na₂CO₃ for 24 h. For the determination of the root density, the root samples were placed on a high-resolution scanner using DT software (Delta-T Scan version 2.04; Delta-T Devices Ltd, Burrwell, Cambridge, UK).

The quinoa seed yield also was determined by manually harvesting the plants of the two central rows of each plot on 15th of September. Saponin content in the seeds was estimated using reverse phase HPLC based on the protocol described by San Martin and Briones (2000). Seeds for extraction (30 g) were thoroughly grounded and then extracted with water at 60°C for 3 h. The ratio of water to seeds was 15 to 1 (by weight). The extract was centrifuged and the supernatant filtered (pore size 0.45 lm) and then analysed by RP-HPLC (Martinez et al., 2009).

**Statistical analysis**

For calculating analysis of variance and comparisons of means, Statistica software (StatSoft Inc, Tulsa, OK, USA) 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.
Results and discussion

Soil properties

The lowest soil porosity and total N were found under CT (Tab. 1). In soil porosity, an interaction between fertilization and tillage system was found. There were statistically significant differences between MT and CT systems. Moreover, there were significant differences between the organic fertilization treatments concerning the soil porosity and total N.

The adoption of conservation tillage practices that include NT or minimum tillage (MT) has been shown to lead to soil improvement: organic matter, porosity, bulk density, aggregate stability and water infiltration rate (Alvarez and Steinbach, 2009; Bilalis et al., 2011; Daraghmeh et al., 2009). In a previous study, it was shown that the soil organic matter and total nitrogen were higher in soils subjected to conservation tillage systems (minimum and no-tillage) than to conventional tillage (Bilalis et al. 2010; Wang et al. 2012).

Quinoa growth and yield

Concerning the root density, there were significant differences between CT and MT systems (Tab. 2). Munoz-Romero et al. (2010) found that the wheat root length was greater under NT than under CT for the most growth stages and depths. Also, there were significant differences in root growth between fertilization treatments. The lowest root diameter was found under control treatment. Root density had positive and significant correlation with soil porosity and total N ($r=0.573$, $p<0.01$, and $r=0.820$, $p<0.001$, respectively). Moreover, the lowest LAI (Tab. 2) and dry weight (Tab. 3) were found under MT. The highest LAI and dry weight was found under cow manure treatment. Data obtained by other researchers (Bilalis et al., 2010; Efthimiadou et al., 2009) clearly demonstrate the

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
</tr>
</thead>
</table>
| Experiment 2010 | \begin{tabular}{|c|c|c|c|c|c|} \hline & Porosity% & N% \hline CT & 39.25 & 42.50 & 39.75 & 0.121 & 0.141 & 0.136 \hline MT & 44.00 & 46.75 & 47.50 & 0.144 & 0.164 & 0.158 \hline \hline $F_{\text{tillage}}$ & 90.21** (LSD$_{5\%}$=1.87) & & & & & \hline $F_{\text{fertilization}}$ & 17.72*** (LSD$_{5\%}$=1.44) & & & & & \hline $F_{\text{tillage}\times\text{fertilization}}$ & 13.24** & & & & & \hline \hline Experiment 2011 | \begin{tabular}{|c|c|c|c|c|c|} \hline & Porosity% & N% \hline CT & 40 & 43.25 & 40.75 & 0.137 & 0.156 & 0.149 \hline MT & 45.50 & 48 & 49.75 & 0.156 & 0.173 & 0.164 \hline \hline $F_{\text{tillage}}$ & 87.60** (LSD$_{5\%}$=2.21) & & & & & \hline $F_{\text{fertilization}}$ & 19.01*** (LSD$_{5\%}$=1.10) & & & & & \hline $F_{\text{tillage}\times\text{fertilization}}$ & 10.01 & & & & & \hline \hline Experiment 2011 | \begin{tabular}{|c|c|c|c|c|c|} \hline & Porosity% & N% \hline CT & 0.88 & 1.04 & 0.99 & 4.08 & 4.45 & 4.36 \hline MT & 1.03 & 1.24 & 1.16 & 4.47 & 4.89 & 4.66 \hline \hline $F_{\text{tillage}}$ & 92.46** (LSD$_{5\%}$=0.042) & & & & & \hline $F_{\text{fertilization}}$ & 45.31*** (LSD$_{5\%}$=0.043) & & & & & \hline $F_{\text{tillage}\times\text{fertilization}}$ & 1.78 & & & & & \hline \hline Experiment 2011 | \begin{tabular}{|c|c|c|c|c|c|} \hline & Root density & LAI \hline CT & 0.91 & 1.10 & 1.05 & 4.35 & 4.70 & 4.60 \hline MT & 1.07 & 1.21 & 1.14 & 4.58 & 5.03 & 4.75 \hline \hline $F_{\text{tillage}}$ & 94.23** (LSD$_{5\%}$=0.039) & & & & & \hline $F_{\text{fertilization}}$ & 47.00*** (LSD$_{5\%}$=0.037) & & & & & \hline $F_{\text{tillage}\times\text{fertilization}}$ & 2.26** & & & & & \hline

F-test ratios are from ANOVA. Significant at *p=0.05, **p=0.01, ***p=0.001, ns: not significant. The LSD (p=0.05) for tillage systems and organic fertilization are also shown.

Tab. 2. Effects of tillage system (conventional tillage: CT, minimum tillage: MT) and organic fertilization (control, cow manure and compost) on root density (cm cm$^{-3}$) and leaf area index (LAI) of quinoa.

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
</tr>
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</table>
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F-test ratios are from ANOVA. Significant at *p=0.05, **p=0.01, ***p=0.001, ns: not significant. The LSD (p=0.05) for tillage systems and organic fertilization are also shown.

Tab. 1. Effects of tillage system (conventional tillage: CT, minimum tillage: MT) and organic fertilization (control, cow manure and compost) on porosity (%) and nitrogen (%) of quinoa.
beneficial effects of manure and compost on the growth and yields of crops (flax maize). Dry weight and LAI had positive and significant correlation with root density \((r=0.850, p<0.001)\) and \((r=0.869, p<0.001)\), respectively.

Yield was influenced by both tillage system and fertilization (Tab. 3). The highest grain yields were found under the MT system. Data obtained by other researchers demonstrate the beneficial effects of reduced tillage on the crops yields. The highest seed yield (1761 kg ha\(^{-1}\)) and oil yield (670 kg ha\(^{-1}\)) of flax \((Linum ustatissimum\) L.) were found under minimum tillage (Bilalis et al., 2010). In addition, soybean \((Glycine max\) L. Merr.) yield was not affected by tillage system (Alvarez and Steinbach, 2009). The lowest seed yield (2415 kg ha\(^{-1}\)) was found under the NT system with control, while the highest (2613 kg ha\(^{-1}\)) was found in cow manure plots. Quinoa responds well to nitrogen fertilizers. Berti et al. (2000) found that the highest quinoa yields were obtained with the highest nitrogen rate (225 kg ha\(^{-1}\)). Moreover, Schulte auf’m Erley et al. (2005) reported that quinoa yielded between 1790 and 3495 kg grain ha\(^{-1}\) and responded strongly to N fertilization. Seed yield had positive and significant correlation with total N, root density and LAI \((r=0.866, p<0.001, r=0.759, p<0.001\) and \(r=0.752, p<0.001\), respectively).

### Saponin content and yield

The assessment of quinoa saponin content is of a great importance for the industry. There are not data available regarding the performance of quinoa growth under limited tillage systems and organic fertilization. The present results indicated that there were no significant differences in saponin content between tillage systems (Tab. 4). Moreover, there were significant differences in saponin content between fertilization treatments. The lowest saponin content was found under control treatment (0.30-0.35%). Martinez et al. (2009) reported higher saponin content in the seeds (1.2%).

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**Tab. 3. Effects of tillage system (conventional tillage: CT, minimum tillage: MT) and organic fertilization (control, cow manure and compost) on dry weight and yield (kg ha\(^{-1}\)) of quinoa**

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Organic fertilization</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 2010</td>
<td></td>
<td>Dry weight</td>
<td>Yield</td>
<td>Dry weight</td>
<td>Yield</td>
<td>Dry weight</td>
<td>Yield</td>
</tr>
<tr>
<td>CT</td>
<td></td>
<td>7947</td>
<td>8320</td>
<td>8158</td>
<td>2175</td>
<td>2450</td>
<td>2374</td>
</tr>
<tr>
<td>MT</td>
<td></td>
<td>8650</td>
<td>9054</td>
<td>8962</td>
<td>2325</td>
<td>2578</td>
<td>2485</td>
</tr>
<tr>
<td>F(_{\text{tillage}})</td>
<td></td>
<td>21.22 ((\text{LSD}_{0.05}=346))</td>
<td>17.83 ((\text{LSD}_{0.05}=97.26))</td>
<td>8320</td>
<td>8158</td>
<td>2175</td>
<td>2450</td>
</tr>
<tr>
<td>F(_{\text{fertilization}})</td>
<td></td>
<td>23.48 ((\text{LSD}_{0.05}=97))</td>
<td>39.52 ((\text{LSD}_{0.05}=50.69))</td>
<td>8650</td>
<td>9054</td>
<td>8962</td>
<td>2325</td>
</tr>
<tr>
<td>F(_{\text{tillagexfertilization}})</td>
<td></td>
<td>0.14e</td>
<td>0.48e</td>
<td></td>
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</tbody>
</table>

**Tab. 4. Effects of tillage system (conventional tillage: CT, minimum tillage: MT) and organic fertilization (control, cow manure and compost) on saponin content (%) and saponin yield (kg ha\(^{-1}\)) of quinoa**

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Organic fertilization</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 2010</td>
<td></td>
<td>Saponin content</td>
<td>Saponin yield</td>
<td>Saponin content</td>
<td>Saponin yield</td>
<td>Saponin content</td>
<td>Saponin yield</td>
</tr>
<tr>
<td>CT</td>
<td></td>
<td>0.30</td>
<td>0.44</td>
<td>0.39</td>
<td>6.58</td>
<td>10.11</td>
<td>9.34</td>
</tr>
<tr>
<td>MT</td>
<td></td>
<td>0.33</td>
<td>0.42</td>
<td>0.70</td>
<td>11.40</td>
<td>10.52</td>
<td></td>
</tr>
<tr>
<td>F(_{\text{tillage}})</td>
<td></td>
<td>5.44 ((\text{LSD}_{0.05}=0.038))</td>
<td>16.71 ((\text{LSD}_{0.05}=0.92))</td>
<td>63.87 ((\text{LSD}_{0.05}=0.024))</td>
<td>53.56 ((\text{LSD}_{0.05}=0.86))</td>
<td>1.74e</td>
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</tr>
<tr>
<td>F(_{\text{fertilization}})</td>
<td></td>
<td>63.87 ((\text{LSD}_{0.05}=0.024))</td>
<td>53.56 ((\text{LSD}_{0.05}=0.86))</td>
<td>1.74e</td>
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<tr>
<td>F(_{\text{tillagexfertilization}})</td>
<td></td>
<td>0.85e</td>
<td>0.85e</td>
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</table>

**Tab. 5. Effects of tillage system (conventional tillage: CT, minimum tillage: MT) and organic fertilization (control, cow manure and compost) on dry weight and yield (kg ha\(^{-1}\)) of flax**

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Organic fertilization</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
<th>Control</th>
<th>Cow manure</th>
<th>Compost</th>
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<tbody>
<tr>
<td>Experiment 2010</td>
<td></td>
<td>Dry weight</td>
<td>Yield</td>
<td>Dry weight</td>
<td>Yield</td>
<td>Dry weight</td>
<td>Yield</td>
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<tr>
<td>CT</td>
<td></td>
<td>7947</td>
<td>8320</td>
<td>8158</td>
<td>2175</td>
<td>2450</td>
<td>2374</td>
</tr>
<tr>
<td>MT</td>
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<td>8650</td>
<td>9054</td>
<td>8962</td>
<td>2325</td>
<td>2578</td>
<td>2485</td>
</tr>
<tr>
<td>F(_{\text{tillage}})</td>
<td></td>
<td>21.22 ((\text{LSD}_{0.05}=346))</td>
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<td>8320</td>
<td>8158</td>
<td>2175</td>
<td>2450</td>
</tr>
<tr>
<td>F(_{\text{fertilization}})</td>
<td></td>
<td>23.48 ((\text{LSD}_{0.05}=97))</td>
<td>39.52 ((\text{LSD}_{0.05}=50.69))</td>
<td>8650</td>
<td>9054</td>
<td>8962</td>
<td>2325</td>
</tr>
<tr>
<td>F(_{\text{tillagexfertilization}})</td>
<td></td>
<td>0.14e</td>
<td>0.48e</td>
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</table>

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F-test ratios are from ANOVA. Significant at *\(p=0.05\), **\(p=0.01\), ***\(p=0.001\), ns: not significant. The LSD \((p=0.05)\) for tillage systems and organic fertilization are also shown.
The saponin yield was influenced by both tillage system and fertilization (Tab. 4). The highest saponin yield was found under the MT system. The lowest saponin yield (8.43 kg ha⁻¹ and 7.70 kg ha⁻¹, for 2011 and 2010, respectively) was found under the NT system with control, while the highest (12.035 kg ha⁻¹ and 11.40 kg ha⁻¹, for 2011 and 2010, respectively) was found in cow manure plots. Saponin yield had positive and significant correlation with total N, root density and LAI \( (r=0.860, p<0.001, r=0.852, p<0.001\) and \( r=0.807, p<0.001\), respectively). Finally, in quinoa measurements, an interaction between fertilization and tillage system was not found.

Conclusions

The present results indicate that the high saponin content of quinoa was produced under the minimum tillage. Moreover, it was found that quinoa which was cultivated under minimum tillage had higher yield. There were significant differences between the fertilization treatments concerning the seed yield and saponin yield as well. The highest saponin content and yield were found in cow manure and compost treatments. Finally, organic fertilization and minimum tillage improved the soil quality.

References


