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Effects of compost and defatted oilseed meals as sustainable organic fertilizer on Cardoon (*Cynara Cardunculus L.*) production in the Mediterranean basin

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Keywords:	cardoon, organic fertilizers, sustainability, biomass production, energy crop, global warming potential
Abstract:	<p>Cardoon (<i>Cynara cardunculus L.</i>) is an herbaceous biomass crop indicated as one of the most suitable energy crop for Southern European environments. The aim of this work is to outline the effects of sustainable organic fertilizers on the aboveground biomass productivity and the global warming potential (GWP) on cardoon production. Two genotypes and seven different fertilizers (N 100 kg ha⁻¹, N 50 kg ha⁻¹, Compost 30 t ha⁻¹, Compost 15 t ha⁻¹ + N 25 kg ha⁻¹, defatted oilseed meal of sunflower 3 t ha⁻¹, defatted oilseed meal of Brassica Carinata 3 t ha⁻¹ and control unfertilized) were evaluated in a split-plot experiment. Defatted oilseed meal of sunflower recorded the higher total dry weight (+10%) and better GWP (-66%) compared to the other organic fertilizers and performing as well as N 100 kg ha⁻¹ both in term of aboveground biomass yield and GWP. Regarding genotypes performance, "Altilis 41" showed the highest aboveground total dry weight (on average 10 t ha⁻¹ y⁻¹), stalk dry weight (on average 7 t ha⁻¹ y⁻¹) and heads dry weights (on average 3 t ha⁻¹ y⁻¹). Our results highlighted that combining suitable genotype and fertilization strategy, could be possible to increase production sustainability of <i>C. cardunculus</i>.</p>

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3 Dear Editor,

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5 please consider the enclosed manuscript **Effects of compost and defatted oilseed**
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7 **meals as sustainable organic fertilizer on Cardoon (*Cynara Cardunculus* L.)**
8
9 **production in the Mediterranean basin** for publication in The Journal of
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11 Horticultural Science and Biotechnology.
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18 The present manuscript investigates the effects of sustainable organic fertilizers on
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20 the aboveground biomass productivity and the global warming potential (GWP) on
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22 cardoon production, over three years of cultivation in the rain fed and temperate
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24 climate conditions of Southern Italy. Two genotypes of *C. cardunculus* var. *altilis*
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26 D.C. cv. “Gobbo di Nizza” and “Altilis 41” were compared as energy crops. Seven
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28 different fertilizers (N 100 kg ha⁻¹, N 50 kg ha⁻¹, Compost 30 t ha⁻¹, Compost 15 t ha⁻¹
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30 + N 25 kg ha⁻¹, defatted oilseed meal of sunflower 3 t ha⁻¹, defatted oilseed meal of
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32 Brassica Carinata 3 t ha⁻¹ and control unfertilized) were evaluated in a split-plot
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34 experiment. This is significant because nowadays farmers are called to increase the
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36 agricultural sustainability and few published paper reported the effects of fertilizers
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38 on cardoon production. We believe that this manuscript is appropriate for publication
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40 by The Journal of Horticultural Science and Biotechnology because it might
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42 contribute in the improvement of cardoon productivity and sustainability.
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55 This manuscript is an unpublished work.
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50 Yours Sincerely

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53 Domenico Ronga
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1
2 **1 Effects of compost and defatted oilseed meals as sustainable organic fertilizer on**
3
4 **2 Cardoon (*Cynara Cardunculus* L.) production in the Mediterranean basin**
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6
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23
24 **11 Abstract**

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26 12 Cardoon (*Cynara cardunculus* L.) is an herbaceous biomass crop indicated as one of the most suitable
27
28 13 energy crop for Southern European environments. The aim of this work is to outline the effects of
29
30 14 sustainable organic fertilizers on the aboveground biomass productivity and the global warming
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32 15 potential (GWP) on cardoon production, over three years of cultivation in the rain fed and temperate
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34 16 climate conditions of Southern Italy. Two genotypes of *C. cardunculus* var. *altilis* D.C. cv. “Gobbo di
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36 17 Nizza” and “Altilis 41”, were compared as energy crops. Seven different fertilizers (N 100 kg ha⁻¹, N
37
38 18 50 kg ha⁻¹, Compost 30 t ha⁻¹, Compost 15 t ha⁻¹ + N 25 kg ha⁻¹, defatted oilseed meal of sunflower 3 t
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40 19 ha⁻¹, defatted oilseed meal of Brassica Carinata 3 t ha⁻¹ and control unfertilized) were evaluated in a
41
42 20 split-plot experiment. *C. cardunculus* was affected by the different nitrogen fertilization treatments
43
44 21 both in term of aboveground biomass yield and GWP. Defatted oilseed meal of sunflower recorded the
45
46 22 higher total dry weight (+10%) and better GWP (-66%) compared to the other organic fertilizers and
47
48 23 performing as well as N 100 kg ha⁻¹ both in term of aboveground biomass yield and GWP. Regarding
49
50 24 genotypes performance, “Altilis 41” showed the highest aboveground total dry weight (on average 10 t
51
52 25 ha⁻¹ y⁻¹), stalk dry weight (on average 7 t ha⁻¹ y⁻¹) and heads dry weights (on average 3 t ha⁻¹ y⁻¹).
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54
55 26 Finally, over the 3-years of cultivation *C. cardunculus* yielded from 12 t ha⁻¹ of total aboveground
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2 27 biomass dry weight in the first year decreasing to 6.0 t ha⁻¹ of the total aboveground biomass dry
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4 28 weight in the third one. Our results highlighted that combining suitable genotype and fertilization
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6 29 strategy, could be possible to increase production sustainability of *C. cardunculus* as energy crop in the
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8 30 Mediterranean area.
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11 31
12 32 **Keywords:** cardoon, organic fertilizers, sustainability, biomass production, energy crop, global
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14 33 worming potential
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19 35 1. INTRODUCTION

20
21 36 An increase of the crop production sustainability is one of the challenges proposed by the European
22
23 37 Community to reduce the dependence on oil consumption, which could improve the security of energy
24
25 38 supply in the medium and long term (Mantineo, D'agosta, Copani, Patanè, & Cosentino, 2009).

26
27 39 Biomasses used to obtain green energy on a global scale, can contribute to improve the environment
28
29 40 sustainability. In fact, when biomasses are burned, they emitted carbon into the atmosphere that
30
31 41 previously was adsorbed during the crop cycle in the photosynthetic process (Royal Society, 2008).

32
33
34 42 Different biomasses can be used in the EU to obtain green energy, such as those from arable crops
35
36 43 currently grown for food: sugar, starch and oil crops, forestry or domestic waste and marine biomass.
37
38 44 On the other hand, using dedicated crops, called “energy crops”, which were bred to produce huge
39
40 45 biomass, could be possible favor their use for energy production (Mantineo, 2009) preserving the crops
41
42 46 cultivated to feed human and animals.

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44
45 47 The use of energy crops presupposes that the obtained energy is significantly higher than that required
46
47 48 to grow, according to Lewandowski & Schmidt (2006).

48
49 49 Simple cropping techniques and low productions costs are the main requirements to produce energy
50
51 50 crops; cardoon (*Cynara cardunculus* L.) is indicated as one of the most suitable for satisfying these
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53 51 requirements in the Mediterranean area (González, González-García, Ramiro, González, Sabio, Gañán,
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55 52 & Rodríguez, 2004).
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1
2 53 Cultivated cardoon (*Cynara Cardunculus* L. var. *altilis* DC) belongs, together with globe artichoke (*C.*
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4 54 *cardunculus* L. var. *scolymus* L.) and wild cardoon (*C. cardunculus* L. var. *sylvestris* (Lamk) Fiori), to
5
6 55 the family *Asteraceae*. Cardoon is an herbaceous plant with polyannual cycle suitable for the
7
8 56 Mediterranean basin (Portis, Barchi, Acquadro, Macua, & Lanteri, 2005). Cultivated cardoon is raised
9
10 57 from seed and handled as an annual plant. Seeds are sown in late Spring and the plants over-summer in
11
12 58 the vegetative state (Portis et al., 2005). The European agricultural area devoted to this crop (2,000–
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14 59 3,000 ha) is mainly confined to a small area and in particularly in Spain, Italy, France and Greece,
15
16 60 where it is used for the preparation of traditional foods (Ierna & Mauromicale, 2010; Portis et al.,
17
18 61 2005).

20
21 62 In recent years, the species *C. cardunculus* has been considered as multipurpose crop. Several
22
23 63 researches have indicated that cardoon is among the most promising species for energy and cellulose
24
25 64 production in the Mediterranean basin (Foti & Cosentino, 2001; Cosentino, Copani, Mantineo, Patané,
26
27 65 & D'Agosta, 2008). In fact, *C. cardunculus* offer a wide spectrum of different biomass uses: for
28
29 66 alternative energy production by combustion, pyrolysis and gasification (Gonzales et al., 2004; Ochoa
30
31 67 & Fandos, 2004); for paper pulp (Gominho, Fernandez, & Pereira, 2001) and for feeding ruminants
32
33 68 (Cajarville, Gonzalez, Repetto, Rodriguez, & Martinez, 1999). Moreover, achens contains oil (25-33%)
34
35 69 with high levels of α -tocopherol, which offers stability against oxidation (Maccarone et al., 1999).
36
37 70 These characteristics make *C. cardunculus* oil suitable for human consumption. Furthermore, research
38
39 71 has been carried out to obtain biodiesel from *C. cardunculus* oil (Lapuerta, Armas, Ballesteros, &
40
41 72 Fenández, 2005). After oil extraction from the seeds, the residual meal could be used for animal feed
42
43 73 (Foti et al., 1999). *C. cardunculus* L. has also been used for medicinal purposes (Kraft, 1997) due to its
44
45 74 richness of polyphenols and inuline into the leaves (Jimenez-Escrig, Dragsted, Daneshvar, Pulido, &
46
47 75 Saura-Calixto, 2003).

50
51 76 The aboveground biomass yield in term of dry weight is, on average, 19.0 t ha⁻¹ (Foti et al., 1999;
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53 77 Maccarone et al., 1999). Moreover, other studies reported that the yield expressed as total energy
54
55 78 obtainable by 1 ha of crop, is greater for cultivated var. *altilis* (cardoon genotypes) compared to var.

1
2 79 *scolymus* (globe artichoke) and var. *sylvestris* (wild cardoon) (Raccuia & Melilli, 2007; Angelini,
3
4 80 Ceccarini, Nassi o Di Nasso, & Bonari, 2009).

5
6 81 Several works carried out in Italy reported an interesting potential yield in terms of biomass and energy
7
8 82 of *C. cardunculus* (Angelini et al., 2009; Piscioneri, Sharma, Baviello, & Orlandini, 2000; Gherbin,
9
10 83 Monteleone, & Tarantino, 2001; Mantineo et al., 2009; Ierna & Mauromicale, 2010); nonetheless,
11
12 84 information on cropping techniques and crop performances showed great variability.

13
14 85 Regarding fertilization, some authors (Mantineo et al., 2009; Ierna & Mauromicale, 2010; González et
15
16 86 al., 2004; Grammelis, Malliopoulou, Basinas, & Danalatos, 2008) investigated the effects of different
17
18 87 chemical nitrogen applications on yield performances of cultivated cardoons. However, to the author's
19
20 88 knowledge, there is lack of information on the effects of organic fertilizers on cardoon production in
21
22 89 literature and, from this point of view, a more comprehensive assessment might be useful to increase
23
24 90 the sustainability of this crop. Therefore, we evaluated the effects of compost and two different defatted
25
26 91 oilseed meals applied as organic fertilizers to cardoon production under over 3-years of Mediterranean
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28 92 climatic conditions. Assessments included effects of fertilizers on the traits influencing the yield
29
30 93 component, aboveground biomass yield and environmental impact.
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36 95 **2. MATERIALS AND METHODS**

37 38 39 40 97 *2.1 Location of the trial*

41
42 98 The agronomic performance of two cultivated cardoon varieties was evaluated in an open field trial at
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44 99 Sele Valley (40°35'03.8"N, 14°58'48.6"E) (Salerno, Southern Italy) during the 3-year periods in a
45
46 100 Typic Haploxerepts soil (Soil Taxonomy, USDA). The physical and chemical soil properties were as
47
48 101 follows: sand 26.8%, silt 40.8%, clay 32.4%, limestone 2.4%, pH 7.8, organic matter 1.6%, total
49
50 102 nitrogen 1.3 ‰, P₂O₅ 126 mg kg⁻¹ and K₂O 324 mg kg⁻¹ (Table 1).
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55 56 104 *2.2 Plant material and crop management*

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2 105 *C. cardunculus* was transplant on May 7th 2010 with a density of 1 plant m⁻² (Table 2). The following
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4 106 factors were studied in a split-plot experimental design with three replicates: two Italian genotypes
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6 107 (Gobbo di Nizza, and Altilis 41, from North/Centre Italy and Sicily, respectively) (Acquadro et al.,
7
8 108 2012) and seven different fertilization management: 1) 100 kg N ha⁻¹ (N100); 2) 50 kg N ha⁻¹ (N50);
9
10 109 compost 30 t ha⁻¹ (C30); 4) compost 15 t ha⁻¹ + 25 kg N ha⁻¹ (C15+N25); 5) defatted seed meal of
11
12 110 *Brassica carinata* (*Brassica carinata* A. Braun) 3 t ha⁻¹ (DMB3); 6) defatted seed meal of sunflower
13
14 111 (*Heliantus annus* L.) 3 t ha⁻¹ (DMS3) and 7) control unfertilized (N0), considering fertilizer as main
15
16 112 plot (69.12 m²) and genotype as sub-plot (34.56 m²).

17
18
19 113 Ammonium nitrate was used as chemical fertilizer. The organic fertilizers showed the following main
20
21 114 characteristics: commercial compost from organic fraction of municipal solid waste (GeSeNu Srl,
22
23 115 Perugia, Italy) (organic C, 279 g kg⁻¹; total N, 21 g kg⁻¹); defatted oilseed meal of *B. carinata*
24
25 116 (organic C, 450 g kg⁻¹; total N, 57 g kg⁻¹) and defatted oilseed meal of sunflower (organic C,
26
27 117 450 g kg⁻¹; total N, 50 g kg⁻¹).

28
29
30 118 Four-week-old plants with four leaves were transplanted, 120 cm apart in rows 80 cm apart. Each plot
31
32 119 consisted of 36 plants. Weeds and pests were controlled according to the production rules of Campania
33
34 120 Region, Italy. In particular, weeds were controlled by not-chemical management using mechanical and
35
36 121 hand hoeing control. As regards the pathogen and pest control, chemical and organic-admitted
37
38 122 fungicides (sulphur) and pesticides (azadirachtin A) were used. The main pests and pathogens observed
39
40 123 were aphids, noctuids e mildew. Regarding N100 and N50 in the first year of the trial, *C. cardunculus*
41
42 124 received one third of the nitrogen fertilizer at transplanting and two thirds at the leaf rosette phase. In
43
44 125 the following years, half dose was applied at plant sprouting in September and half dose at stalk
45
46 126 elongation in April–May. Compost and defatted oilseed meals were administered before transplanting.
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48 127 The crop, since it dries off, was only irrigated in the first year after transplanting and again in
49
50 128 September in the second and third year with just light watering, in order to activate sprouting.
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52 129 During the crop cycle (Figure 1) the main weather data were recorded (Table 2).
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2 130 At harvest, above ground biomass and its partitioning (stalks + leaves and heads) were determined.
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4 131 Crops were harvested when the humidity content was about 13%. Moisture content of each plant part
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6 132 was calculated by drying samples at 65 °C in a thermo-ventilated oven until constant weight was
7
8 133 achieved.

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11 135 *2.3 Data collection*

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14 136 During the 3 years of the experiment, the inputs for crop production were minimized and all the
15
16 137 agricultural operations were recorded.

17
18 138 The plants were grown for dry aboveground biomass, leaving all the heads maturing achenes. At the
19
20 139 end of each annual crop cycle, at complete maturation of achenes, number of heads and number of
21
22 140 stalks per plant and plant height, were determined. The harvest of above-ground biomass, heads
23
24 141 enclosed, was carried out on 7th September 2011, 28th August 2012 and 16th September 2013. Ten
25
26 142 plants standing in the middle of each plot were harvested; plants bordering each side of a plot were
27
28 143 discarded. The plants were cut at ground level and immediately were weighed in open field, in order to
29
30 144 determine the fresh weight (f. w.) of biomass components (stalks + leaves and heads). In the laboratory,
31
32 145 the moisture content was measured by weighing 100 g of plant material in a precalibrated aluminum
33
34 146 container and placing it in a thermoventilated oven at 105 °C until constant weight was reached.
35
36 147 Biomass yield were expressed as g m⁻² of dry weight (d.w.). The stalks plus leaves and heads incidence
37
38 148 on total above-ground biomass was calculated.
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45 150 *2.4 Environmental assessment methodology*

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47 151 Greenhouse gas (GHG) emissions valuation by Life Cycle Assessment (LCA) was performed. The
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49 152 LCA analysis was used, considering entire life cycle at farm gate, providing a method to assess
50
51 153 different fertilization performances. One hectare (ha) of cultivation and 1 ton (t) of harvest biomass (d.
52
53 154 w.) were used as functional units (FU) to study the potential environmental impacts of cardoon
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55 155 production. Global warming potential (GWP) was adopted as the impact category for this study.
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1 156 Functional units expressed in kg CO₂-equivalents (CO₂-eq), were obtained using Tier 2 methodologies
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4 157 recommended by the IPCC (2006).

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6 158 The study considered the process from the soil tillage to the harvest time of the crop.

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8 159 Most data related to energy consumption, were recorded during the crop cycles; in addition, available
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10 160 data were also used as electrical energy (EPA, 2014; Pehnt, 2006) gasoline, lubricant (Furuholt, 1995;
11
12 161 Cuevas, 2005) and fertilizer production (Mazzoncini et al., 2015; Skowrońska & Filipek, 2013; Hesq &
13
14 162 Jensen, 2010). Emissions from diesel combustion were referred to EEA (2013) guidebook. Direct and
15
16 163 indirect N₂O emissions from fertilizers and residues were calculated following IPCC (2006) tier 1,
17
18 164 considering a reduction of 28% observed for solid organic fertilizers (Aguilera, Lassaletta, Sanz-
19
20 165 Cobena, Garnier, & Vallejo, 2013). Impact of seeds, seedlings, pesticides and fungicides production, as
21
22 166 well as manufacture and maintenance of farm's equipment, their transport and their waste management,
23
24 167 were omitted in the analysis due to the same contribution on the different fertilization treatments
25
26 168 (Meisterling, Samaras, & Schweizer, 2009).
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31 170 *2.5 Data analysis*

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34 171 Data were analyzed using analysis of variance (ANOVA). Means were statistically separated on the
35
36 172 basis of Tukey test, when the 'F' test of ANOVA for treatment was significant at least at the 0.05
37
38 173 probability level. Experimental data were processed for a principal component analysis (PCA) using
39
40 174 PLS Toolbox software (Eigenvector Research Inc, Wenatchee, WA, USA), in order to evaluate the
41
42 175 existing relationships with original variables.
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47 177 **3. RESULTS AND DISCUSSION**

48
49 178 During the 3 years of the trial, monthly temperature and rainfall were measured by a weather station in
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51 179 the experimental field. The site was mainly characterized by air temperatures, with minimum values
52
53 180 ranging from 10.0 to 12.4 °C and maximum values ranging from 17.2 to 21.8 °C. There was
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1
2 181 considerable variability in rainfall and its distribution from year to year. The mean annual amounts of
3
4 182 rainfall observed over the 3-years, were 670 mm, 990 mm and 360 mm, respectively.
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8 184 *3.1 Aboveground biomass production and its partitioning.*
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10 185 The use of renewable sources as fertilizers could increase the agricultural sustainability. In this point of
11
12 186 view, the valorization of agro-industrial byproducts such as organic wastes, may represent an
13
14 187 opportunity to reduce the environmental impact related to chemical fertilizer production and use
15
16 188 improving soil fertility (Mazzoncini et al., 2015; Zaccardelli, Vилlecco, Celano, & Scotti, 2013).
17

18
19 189 Defatted oilseed meals show an interesting economic value as feed for animals, whilst their value as
20
21 190 organic nitrogen fertilizers were not fully explored (Mazzoncini et al., 2015) especially for the
22
23 191 production of energy crops.
24

25 192 In the present study, results of the analysis of variance for all studied variables showed interesting
26
27 193 differences among fertilizers, genotypes and years (Table 3), while no significant interactions were
28
29 194 showed among the investigated variables.
30

31
32 195 At complete maturation of achenes, the main traits influencing the yield component such as number of
33
34 196 stalks and heads *per* plant and plant height, were recorded.
35

36 197 Regarding the number of stalks, genotype “Gobbo di Nizza” recorded the higher production +29%
37
38 198 respect to “Altilis 41” and, in the first year of cultivation, was recorded the lower production, -41%,
39
40 199 compared to the other two years.
41

42
43 200 The number of heads was affected by fertilizer, genotype and year. N100 recorded the highest value
44
45 201 (+46%) compared to the unfertilized treatment. However, the other fertilizers showed similar values to
46
47 202 N100, except for DMB3 and N0. “Altilis 41” recorded the higher value (+16%) compared to “Gobbo di
48
49 203 Nizza”. The first year was the more productive (+18% and +54%) respect to the second and the third
50
51 204 ones, respectively.
52

53 205 Regarding the eight of the plants, no effects were recorded by fertilization treatments, while “Gobbo di
54
55 206 Nizza” showed the higher value (+5%) than “Altilis 41”. The effect of the year highlighted a similar
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207 trend noticed for the number of heads. In the first year, was recorded the highest value (+5% and
208 +26%) compared to the second and the third ones.

209 About the most important trait, aboveground biomass, N100 recorded the higher value of stalks and
210 leaves dry weight (+73%) followed by DMS3 (+14%) compared to unfertilized treatment, respectively.

211 Genotype “Atilis 41” showed the higher value (+13%) and, in the first year, was recorded the highest
212 production, +62% and +100%, compared to the second and the third ones, respectively.

213 No differences were recorded for heads dry weights among the different fertilization treatments, while
214 genotype “Atilis 41” highlighted the higher value (+46%) than “Gobbo di Nizza”; the first year was
215 the most productive (+24% and +113%) than the second and the third ones, respectively.

216 Total dry weight of cardoon was affected by fertilizer, genotype and year, showing a similar trend
217 reported for stalks and leaves dry weighs. When ammonium nitrate was applied at 100 kg ha⁻¹ (N100)
218 total dry weight production increased by 65% respect to N0 (Table 3). DMS3 and N50 produced a
219 similar effect to N100 but at lower level (+14% and +11%, respectively) compared to N0. Genotype
220 “Atilis 41” highlighted the higher value (+21%) than “Gobbo di Nizza”; the first year was the most
221 productive (+51% and +100%) than the second and the third ones, respectively.

222 Our data confirming the hypothesis reported by Portis et al. (2005) who highlighted that cultivated
223 cardoon behaviors can be considered as an annual crop. Moreover, as showed by Raccuia & Melilli
224 (2007) the radical apparatus progressively grows deeper, hence the differences due to the age of the
225 crop were more obvious after the first year of cultivation.

226 Another important trait in biomass production is the biomass partitioning. The fertilization N50
227 increased the biomass allocated to heads, showing the highest value (+11%) respect to the general
228 average. Genotype “Atilis 41” performed better than “Gobbo di Nizza”, allocating +20% of the total
229 biomass in the heads. In the second year was registered the highest value of allocation (+27% and
230 +40%) respect to of the first and the third year, respectively.

1
2 231 Finally, regarding the average weight of the heads, no effects were recorded by the different fertilizers.
3
4 232 Genotype “Altilis 41” performed better than “Gobbo di Nizza” (+26%) while, in the second year, was
5
6 233 recorded the highest value (+5% and +36%) respect to the first and the last ones, respectively.
7
8 234 Summarizing our results, DMS3 could be a sustainable organic fertilizer for the production of
9
10 235 cultivated cardoon. Similar results were obtained by Mazzoncini et al. (2015) working on vegetable
11
12 236 crops such as lettuce, chard and spinach. The lower agronomical performance of DMB3 was putatively
13
14 237 due to the content of glucosinolates that may reduce the availability of nitrogen and/or inhibit the effect
15
16 238 on nitrification processes (Mazzoncini et al., 2015).
17
18 239 Zaccardelli et al. (2013) reported a significant positive response of the soil enzymatic activities due to
19
20 240 the addition of seed meals for the eggplant production, indicating a beneficial effect on soil quality. In
21
22 241 addition, Zaccardelli et al. (2013) showed that defatted oilseed meals, compared to compost,
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24 242 highlighted an increase of soil enzymatic activities only in the first two months after application,
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26 243 reflecting the rate of release of nutrients, such as mineral fertilizers. Hence, the lower release of
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28 244 nutrients showed by compost could be negatively affects the cardoon production in the present work.
29
30 245 However, further investigations are required to confirm this hypothesis.
31
32 246 In the preset study, “Altilis 41” performed better than “Gobbo di Nizza”, reflecting its suitability for the
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34 247 investigated environment (Acquadro et al., 2012).
35
36 248 About biomass production, the results recorded in the present study are in agreement with Fernández
37
38 249 (1998), that reported a biomass production of *C. cardunculus* from 10 to 20 t of d.w. ha⁻¹ year⁻¹, if the
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40 250 crop is well established and rainfall is about 500 mm year⁻¹. Also González et al. (2004) recorded an
41
42 251 aerial biomass production (about 11 t ha⁻¹ of d. w.) similar to our results.
43
44 252 Moreover, our results regarding biomass production, dry weight distribution, number of heads and
45
46 253 plant height, were in agreement with those reported in an interesting study conducted by Ierna &
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48 254 Mauromicale (2010). The authors cropped genotype “Cardo gigante di Romagna” under low input crop
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50 255 management applying 80 kg ha⁻¹ of nitrogen as ammonium nitrate.
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1
2 256 On the other hand, comparing our results with those obtained under high input management, the
3
4 257 maximum yield recorded in the present study was lower (about -50%) respect that one reported by
5
6 258 Mantineo et al. (2009) who, however, used a different genotype (*Cardo gigante inerme*) with high
7
8 259 irrigation and fertilizer treatment (irrigation as 75% of evapotranspired water and fertilization as 100
9
10 260 kg ha⁻¹ of nitrogen). Nonetheless, similar to our results, a lower aboveground biomass yield (less than
11
12 261 1 t ha⁻¹ of d. w.) in the last year of cultivation was registered.

14 262 Cardoon needs less nitrogen than many other crops. In many field experiments, high biomass yields
15
16 263 were attainable under fertilization dressings from 0 up to 50 kg of N ha⁻¹ (Grammelis et al., 2008). In
17
18 264 fact, an interesting point was observed with compost fertilization. In the present study, 30 t ha⁻¹,
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20 265 corresponding to about 600 kg N ha⁻¹, were applied and a biomass production similar to unfertilized
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22 266 treatment was registered.

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27 268 *3.2 Relationships among the recorded parameter, fertilization, genotype and years*

29 269 The correlation between recorded parameters, genotype, fertilization treatments and year was studied
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31 270 by means of PCA. Figure 2 reports the biplots of the PCA models calculated tacking in account the data
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33 271 recorded during the 3-year of cultivations. In the PCA model, the two first components represented
34
35 272 more than half of variation in the datasets, PC1 accounts for 30.14% and PC2 for 27.51%. It was no
36
37 273 possible to identify clear separations into clusters: therefore, the results are described in relation to the
38
39 274 most important parameter, such as total dry weight. In general, total dry weight, average weight of
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41 275 heads, dry weight of heads and biomass allocated to heads, are highly associated, since they are close
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43 276 each other (Figure 2).

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45
46 277 PC1 clearly highlights the effects of the number of stalks and the biomass allocated to stalks plus leaves
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48 278 on total dry weight, while PC2 is mainly related to the difference between the morphological and
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50 279 yielding traits regarding the heads.

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52
53 280 Year 2012 was in the middle between years 2011 and 2013, overlapping in some points. This fact
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55 281 confirms the annual variation showed in Table 3. The yearly variability due to different weather

1
2 282 condition, as reported in the present study, was highlighted also in other studies conducted in a similar
3
4 283 area (Rinaldi, Convertini, & Elia, 2007; Ronga et al., 2015). Moreover, the differences recorded
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6 284 between the two growing seasons were putatively ascribed at the different weather condition between
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8 285 the three years. In fact, 2013 was drier and colder than 2012 and 2011 (Table 2), probably causing the
9
10 286 longest crop cycle (Table 2) and the lowest biomass production (Table 3). In fact, the production of
11
12 287 aboveground biomass on *C. cardunculus* depends on the presence of water in the soil, especially in dry
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14 288 conditions and the adequate fertilization of the crop. In experiences carried out in several countries of
15
16 289 the Mediterranean zone, was highlighted a high correlation between the rainfall of the year and the total
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18 290 biomass production of cardoon, especially with the rainfall occurred during Spring (González et al.,
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20 291 2004).

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25 293 *3.3 Environmental impact*

27 294 The GWP of cardoon production *per* area is reported in Figure 3a; the higher impact recorded in the
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29 295 present study was mainly due to GHG emissions to produce fertilizers, followed by direct and indirect
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31 296 emission and, then, by agricultural operations (data not shown). Among treatments, N0 had the lowest
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33 297 impact *per* hectare, followed by N50 and defatted oilseed meals (Figure 3a). On the other hand, the
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35 298 impact *per* total biomass was obviously lower for unfertilized treatment than fertilized ones. In fact,
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37 299 opposite results were observed using 1 t of harvested biomass (d. w.) as FU (Figure 3b). Treatment C30
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39 300 achieved a higher impact (+230% on the average impact), due to low yield (-10% on the average yield)
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41 301 (Table 3). An interesting result was showed by the impact of defatted oilseed meal of sunflower meal
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43 302 that was lower *per* unit area compared to N100 treatment and remained similar when computed *per* t of
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45 303 harvest d. w., showing about 240 kg CO₂eq *per* t of d. w.

47 304 In particular, among the investigated organic fertilizers, DMS3 caused the lowest impact *per* hectare
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49 305 and total biomass, and some similar results were reported by Mazzoncini et al. (2015) on vegetables
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51 306 crop.

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2 307 Moreover, our results regarding GWP, both per cropped area and crop yield, are comparable with those
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4 308 reported by Cocco et al. (2014) and Razza et al. (2015) who investigated the life cycle assessment of
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6 309 cardoon cropped in Southern Europe and Sardinia and Sicily, respectively.
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9 10 311 **4. Conclusions**

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12 312 Following 3 years of observation, organic fertilizer could be a sustainable approach for the cardoon
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14 313 production in the environment of Southern Italy. Defatted oilseed meal of sunflower may be properly
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16 314 used as organic fertilizers for cardoon production, ensuring yields comparable with those obtained
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18 315 using mineral nitrogen fertilizer. The present study showed the higher efficacy of defatted oilseed meal
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20 316 of sunflower in sustaining aboveground biomass yield when compared to *B. carinata* meal and
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22 317 compost. The GWP of defatted oilseed meal of sunflower was also better than the *B. carinata* meal and
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24 318 compost footprints. Overall, our findings confirmed the high value of oilseed meals as a sustainable
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26 319 alternative to mineral fertilizers and an important nutrient source also for cardoon production. From the
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28 320 agricultural point of view, the success of the application of defatted oilseed meal of sunflower increase
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30 321 the agricultural sustainability. In conclusion, the potential of cardoons as energy crop in Mediterranean
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32 322 cropping systems under sustainable inputs managements is confirmed in terms of aboveground biomass
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34 323 production. However, future research investments are required to increase and optimize yield and GWP
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36 324 of cardoon production.
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44
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48
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50
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52
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1 333

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Table 1. Soil characteristics of the investigated field

Soil characteristics	
Sand (%)	26.8
Silt (%)	40.8
Clay (%)	32.4
pH	7.8
Limestone (%)	2.4
K₂O (mg/Kg)	324.0
P₂O₅ (mg/kg)	126.0
N. tot. (‰)	1.3
Organic matter (%)	1.6
CSC (meq/100 g)	18.3

Table 2. Transplant and harvest dates and weather conditions recorded during the three trial growing seasons

Year	Location (Lat Long)	Transplant date	Harvest date	Average T min (°C)	Average T max (°C)	Total rainfall (mm)
2011	CRA-ORT 40°35'03.8"N, 14°58'48.6"E	07/05/2010	07/09/2011	12.4	21.8	670
2012	CRA-ORT 40°35'03.8"N, 14°58'48.6"E	-	28/08/2012	11.4	21.0	990
2013	CRA-ORT 40°35'03.8"N, 14°58'48.6"E	-	16/09/2013	10.0	17.2	360
Average				11.3	20.0	673

Table 3. Yield-related agronomical traits, at harvest time, of two cardoon cultivars, over three years of cultivation in Southern Italy.

Source of Variation	Number of stalk (no. plant ⁻²)		Number of heads (no. plant ⁻²)		Height of plant (m)		Dry weight of stalk and leaves (g m ⁻²)		Dry weight of heads (g m ⁻²)		Total dry weight (g m ⁻²)		Fraction of total dry weights to heads		Average weight of heads (g)	
Fertilizer																
N100	2.7		13.5	a	2.4		965.6	a	300.1		1265.2	a	23.3	c	21.5	
N50	2.5		10.8	ab	2.2		617.7	b	246.1		864.2	ab	29.4	a	22.1	
C30	2.4		9.6	ab	2.1		613.5	b	200.8		814.4	b	24.3	bc	19.8	
C15 + N 25	2.4		10.1	ab	2.2		571.9	b	222.2		794.6	b	27.2	abc	21.1	
DMB3	2.3		8.9	b	2.1		579.2	b	200.9		780.1	b	25.9	abc	21.2	
DMS3	2.3		10.6	ab	2.2		633.3	ab	241.1		874.6	ab	27.8	ab	21.6	
N0	2.2		9.2	b	2.1		556.3	b	206.8		762.9	b	26.7	abc	21.7	
P-value	n.s.		<0.05		n.s.		<0.05		ns		<0.05		<0.05		ns	
Cultivar																
Gobbo di Nizza	2.7	a	9.6	b	2.2	a	609.4	b	187.9	b	797.3	b	24.0	b	18.8	b
Altilis 41	2.1	b	11.1	a	2.1	b	687.5	a	274.4	a	961.4	a	28.8	a	23.7	a
p-value	<0.001		<0.01		<0.01		<0.05		<0.001		<0.001		<0.001		<0.001	
Year																
2011	1.6	b	12.5	a	2.4	a	914.6	a	305.4	a	1220.0	a	24.9	b	22.9	b
2012	2.7	a	10.6	b	2.3	b	563.5	b	245.1	b	808.6	b	31.6	a	24.0	a
2013	2.8	a	8.1	c	1.9	c	466.7	b	143.0	c	609.5	c	22.6	c	16.9	c
P-value	<0.001		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	

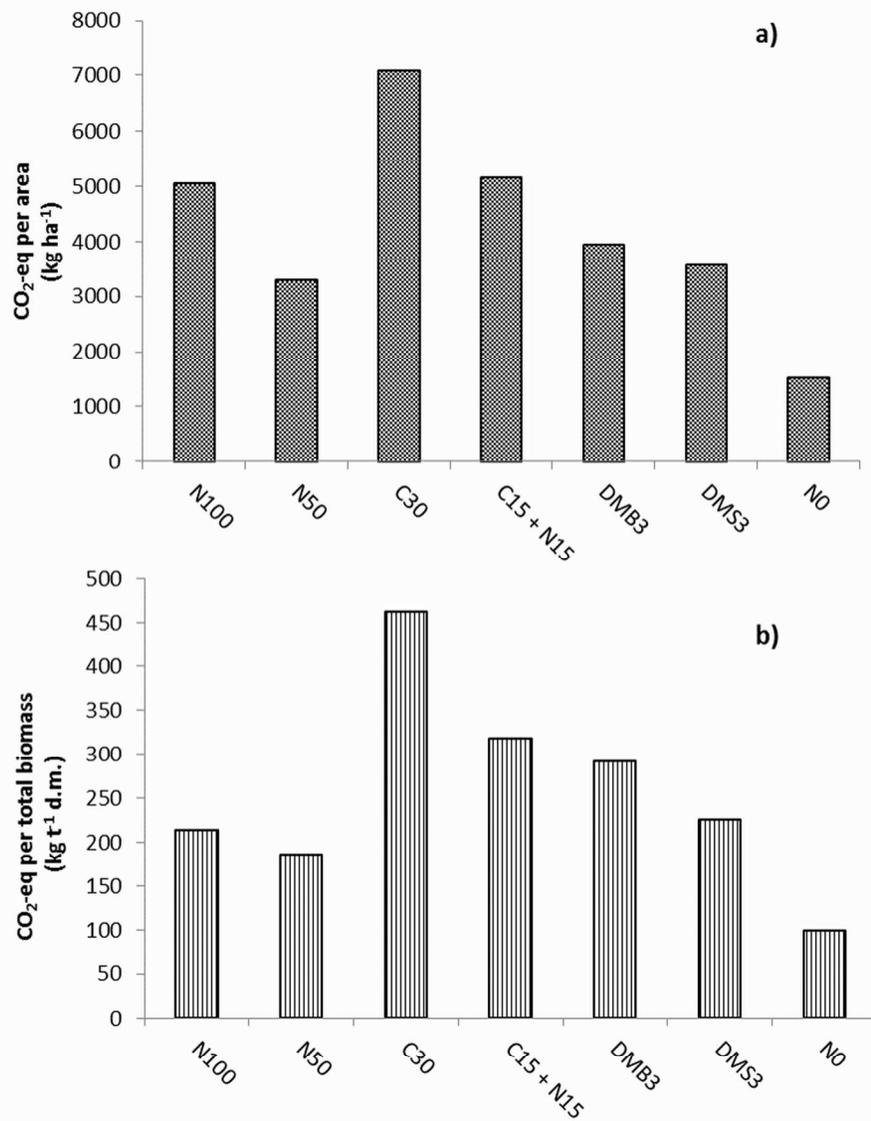
Notes. Mean values (n = 10) within a column followed by different lowercase letters are significantly different at P < 0.05 according to Tukey's test. n.s. = not significant. N100 = 100 kg N ha⁻¹; N50 = 50 kg N ha⁻¹; C30 = compost 30 t ha⁻¹; C15 + N25 = compost 15 t ha⁻¹ + 25 kg N ha⁻¹; DMS3 = defatted meal of sunflower 3 t ha⁻¹; DMB3 = defatted meal of brassica carinata 3 t ha⁻¹; N0 = 0 kg N ha⁻¹.

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1219x183mm (72 x 72 DPI)

For Peer Review Only



833x1013mm (72 x 72 DPI)

1 **Figure 1.** Cardoon growth cycle: vegetative stage (on the left), reproductive stage (on the middle) and
2 harvest stage (on the right).
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10 **Figure 2.** Ordination biplots of principal component analysis outputs. Labels in the graph indicate the
11 investigated treatments, genotypes and years (red diamonds = 2011, green square = 2012 and blue
12 triangle = 2013) and recorded traits (represented by black circles). 1- = Gobbo di Nizza. 2- = Altilis 41.
13 N100 = 100 kg N ha⁻¹; N50 = 50 kg N ha⁻¹; C30 = compost 30 t ha⁻¹; C15 + N25 = compost 15 t ha⁻¹ +
14 25 kg N ha⁻¹; DMS3 = defatted meal of sunflower 3 t ha⁻¹; DMB3 = defatted meal of brassica carinata 3
15 t ha⁻¹; N0 = 0 kg N ha⁻¹. NS = numbers of stalks; FTDWH = fraction of total dry weight to heads;
16 DWH = dry weight of heads; AWH = average fresh weights of heads; TWD = total dry weight of plant;
17 FTWDSL = fraction of total dry weight to stalks; NP = number of plants; HP = height of plants; NH =
18 number of heads; DWSL = dry weights of stalks.
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33 **Figure 3.** Impact on global warming per: (a) area unit (CO₂-eq per hectare); (b) total biomass unit
34 (CO₂-eq per kg of total crop aboveground dry matter). Crops were fertilized with N100 = 100 kg N ha⁻¹;
35 N50 = 50 kg N ha⁻¹; C30 = compost 30 t ha⁻¹; C15 + N25 = compost 15 t ha⁻¹ + 25 kg N ha⁻¹; DMS3
36 = defatted meal of sunflower 3 t ha⁻¹; DMB3 = defatted meal of brassica carinata 3 t ha⁻¹; N0 = 0 kg N
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