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

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Abstract:	Cardoon (Cynara cardunculus L.) 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 worming 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 C. cardunculus.

Dear Editor,

please consider the enclosed manuscript **Effects of compost and defatted oilseed meals as sustainable organic fertilizer on Cardoon (*Cynara Cardunculus* L.) production in the Mediterranean basin** for publication in The Journal of Horticultural Science and Biotechnology.

The present manuscript investigates the effects of sustainable organic fertilizers on the aboveground biomass productivity and the global worming potential (GWP) on cardoon production, over three years of cultivation in the rain fed and temperate climate conditions of Southern Italy. Two genotypes of *C. cardunculus* var. altilis D.C. cv. “Gobbo di Nizza” and “Altilis 41” were compared as energy crops. 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. This is significant because nowadays farmers are called to increase the agricultural sustainability and few published paper reported the effects of fertilizers on cardoon production. We believe that this manuscript is appropriate for publication by The Journal of Horticultural Science and Biotechnology because it might contribute in the improvement of cardoon productivity and sustainability.

This manuscript is an unpublished work.

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Domenico Ronga

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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Abstract

Cardoon (*Cynara carduncul*us L.) 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 worming potential (GWP) on cardoon production, over three years of cultivation in the rain fed and temperate climate conditions of Southern Italy. Two genotypes of *C. cardunculus* var. altilis D.C. cv. "Gobbo di Nizza" and "Altilis 41", were compared as energy crops. 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. *C. cardunculus* was affected by the different nitrogen fertilization treatments both in term of aboveground biomass yield and GWP. 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}). Finally, over the 3-years of cultivation *C. cardunculus* yielded from 12 t ha^{-1} of total aboveground

biomass dry weight in the first year decreasing to 6.0 t ha^{-1} of the total aboveground biomass dry weight in the third one. Our results highlighted that combining suitable genotype and fertilization strategy, could be possible to increase production sustainability of *C. cardunculus* as energy crop in the Mediterranean area.

Keywords: cardoon, organic fertilizers, sustainability, biomass production, energy crop, global worming potential

1. INTRODUCTION

An increase of the crop production sustainability is one of the challenges proposed by the European Community to reduce the dependence on oil consumption, which could improve the security of energy supply in the medium and long term (Mantineo, D'agosta, Copani, Patanè, & Cosentino, 2009). Biomasses used to obtain green energy on a global scale, can contribute to improve the environment sustainability. In fact, when biomasses are burned, they emitted carbon into the atmosphere that previously was adsorbed during the crop cycle in the photosynthetic process (Royal Society, 2008). Different biomasses can be used in the EU to obtain green energy, such as those from arable crops currently grown for food: sugar, starch and oil crops, forestry or domestic waste and marine biomass. On the other hand, using dedicated crops, called "energy crops", which were bred to produce huge biomass, could be possible favor their use for energy production (Mantineo, 2009) preserving the crops cultivated to feed human and animals.

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

Simple cropping techniques and low productions costs are the main requirements to produce energy crops; cardoon (*Cynara cardunculus* L.) is indicated as one of the most suitable for satisfying these requirements in the Mediterranean area (González, González-García, Ramiro, González, Sabio, Gañán, & Rodríguez, 2004).

Cultivated cardoon (*Cynara Carduncululus* L. var. *altilis* DC) belongs, together with globe artichoke (*C. carduncululus* L. var. *scolymus* L.) and wild cardoon (C. *carduncululus* L. var. *sylvestris* (Lamk) Fiori), to the family *Asteraceae*. Cardoon is an herbaceous plant with polyannual cycle suitable for the Mediterranean basin (Portis, Barchi, Acquadro, Macua, & Lanteri, 2005). Cultivated cardoon is raised from seed and handled as an annual plant. Seeds are sown in late Spring and the plants over-summer in the vegetative state (Portis et al., 2005). The European agricultural area devoted to this crop (2,000–3,000 ha) is mainly confined to a small area and in particularly in Spain, Italy, France and Greece, where it is used for the preparation of traditional foods (Ierna & Mauromicale, 2010; Portis et al., 2005).

In recent years, the species *C. carduncululus* has been considered as multipurpose crop. Several researches have indicated that cardoon is among the most promising species for energy and cellulose production in the Mediterranean basin (Foti & Cosentino, 2001; Cosentino, Copani, Mantineo, Patané, & D'Agosta, 2008). In fact, *C. carduncululus* offer a wide spectrum of different biomass uses: for alternative energy production by combustion, pyrolysis and gasification (Gonzàles et al., 2004; Ochoa & Fandos, 2004); for paper pulp (Gominho, Fernandez, & Pereira, 2001) and for feeding ruminants (Cajarville, Gonzalez, Repetto, Rodrìguez, & Martìnez, 1999). Moreover, achens contains oil (25-33%) with high levels of α-tocopherol, which offers stability against oxidation (Maccarone et al., 1999). These characteristics make *C. carduncululus* oil suitable for human consumption. Furthermore, research has been carried out to obtain biodiesel from *C. carduncululus* oil (Lapuerta, Armas, Ballesteros, & Fenàndez, 2005). After oil extraction from the seeds, the residual meal could be used for animal feed (Foti et al., 1999). *C. carduncululus* L. has also been used for medicinal purposes (Kraft, 1997) due to its richness of polyphenols and inuline into the leaves (Jimenez-Escrig, Dragsted, Daneshvar, Pulido, & Saura-Calixto, 2003).

The aboveground biomass yield in term of dry weight is, on average, 19.0 t ha^{-1} (Foti et al., 1999; Maccarone et al., 1999). Moreover, other studies reported that the yield expressed as total energy obtainable by 1 ha of crop, is greater for cultivated var. *altilis* (cardoon genotypes) compared to var.

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

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

Regarding fertilization, some authors (Mantineo et al., 2009; Ierna & Mauromicale, 2010; González et al., 2004; Grammelis, Malliopoulou, Basinas, & Danalatos, 2008) investigated the effects of different chemical nitrogen applications on yield performances of cultivated cardoons. However, to the author's knowledge, there is lack of information on the effects of organic fertilizers on cardoon production in literature and, from this point of view, a more comprehensive assessment might be useful to increase the sustainability of this crop. Therefore, we evaluated the effects of compost and two different defatted oilseed meals applied as organic fertilizers to cardoon production under over 3-years of Mediterranean climatic conditions. Assessments included effects of fertilizers on the traits influencing the yield component, aboveground biomass yield and environmental impact.

2. MATERIALS AND METHODS

2.1 Location of the trial

The agronomic performance of two cultivated cardoon varieties was evaluated in an open field trial at Sele Valley (40°35'03.8"N, 14°58'48.6"E) (Salerno, Southern Italy) during the 3-year periods in a Typic Haploxerepts soil (Soil Taxonomy, USDA). The physical and chemical soil properties were as follows: sand 26.8%, silt 40.8%, clay 32.4%, limestone 2.4%, pH 7.8, organic matter 1.6%, total nitrogen 1.3 ‰, P_2O_5 126 mg kg^{-1} and K_2O 324 mg kg^{-1} (Table 1).

2.2 Plant material and crop management

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

Ammonium nitrate was used as chemical fertilizer. The organic fertilizers showed the following main characteristics: commercial compost from organic fraction of municipal solid waste (GeSeNu Srl, Perugia, Italy) (organic C, 279 g kg^{-1}; total N, 21 g kg^{-1}); defatted oilseed meal of *B. carinata* (organic C, 450 g kg^{-1}; total N, 57 g kg^{-1}) and defatted oilseed meal of sunflower (organic C, 450 g kg^{-1}; total N, 50 g kg^{-1}).

Four-week-old plants with four leaves were transplanted, 120 cm apart in rows 80 cm apart. Each plot consisted of 36 plants. Weeds and pests were controlled according to the production rules of Campania Region, Italy. In particular, weeds were controlled by not-chemical management using mechanical and hand hoeing control. As regards the pathogen and pest control, chemical and organic-admitted fungicides (sulphur) and pesticides (azadirachtin A) were used. The main pests and pathogens observed were aphids, noctuids e mildew. Regarding N100 and N50 in the first year of the trial, *C. cardunculus* received one third of the nitrogen fertilizer at transplanting and two thirds at the leaf rosette phase. In the following years, half dose was applied at plant sprouting in September and half dose at stalk elongation in April–May. Compost and defatted oilseed meals were administered before transplanting. The crop, since it dries off, was only irrigated in the first year after transplanting and again in September in the second and third year with just light watering, in order to activate sprouting.

During the crop cycle (Figure 1) the main weather data were recorded (Table 2).

At harvest, above ground biomass and its partitioning (stalks + leaves and heads) were determined. Crops were harvested when the humidity content was about 13%. Moisture content of each plant part was calculated by drying samples at 65 °C in a thermo-ventilated oven until constant weight was achieved.

2.3 Data collection

During the 3 years of the experiment, the inputs for crop production were minimized and all the agricultural operations were recorded.

The plants were grown for dry aboveground biomass, leaving all the heads maturing achenes. At the end of each annual crop cycle, at complete maturation of achenes, number of heads and number of stalks per plant and plant height, were determined. The harvest of above-ground biomass, heads enclosed, was carried out on 7th September 2011, 28th August 2012 and 16th September 2013. Ten plants standing in the middle of each plot were harvested; plants bordering each side of a plot were discarded. The plants were cut at ground level and immediately were weighed in open field, in order to determine the fresh weight (f. w.) of biomass components (stalks + leaves and heads). In the laboratory, the moisture content was measured by weighing 100 g of plant material in a precalibrated aluminum container and placing it in a thermoventilated oven at 105 °C until constant weight was reached. Biomass yield were expressed as g m^{-2} of dry weight (d.w.). The stalks plus leaves and heads incidence on total above-ground biomass was calculated.

2.4 Environmental assessment methodology

Greenhouse gas (GHG) emissions valuation by Life Cycle Assessment (LCA) was performed. The LCA analysis was used, considering entire life cycle at farm gate, providing a method to assess different fertilization performances. One hectare (ha) of cultivation and 1 ton (t) of harvest biomass (d. w.) were used as functional units (FU) to study the potential environmental impacts of cardoon production. Global warming potential (GWP) was adopted as the impact category for this study.

Functional units expressed in kg CO_2-equivalents (CO_2-eq), were obtained using Tier 2 methodologies recommended by the IPCC (2006).

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

Most data related to energy consumption, were recorded during the crop cycles; in addition, available data were also used as electrical energy (EPA, 2014; Pehnt, 2006) gasoline, lubrificant (Furuholt, 1995; Cuevas, 2005) and fertilizer production (Mazzoncini et al., 2015; Skowrońska & Filipek, 2013; Hesq & Jenssen, 2010). Emissions from diesel combustion were referred to EEA (2013) guidebook. Direct and indirect N_2O emissions from fertilizers and residues were calculated following IPCC (2006) tier 1, considering a reduction of 28% observed for solid organic fertilizers (Aguilera, Lassaletta, Sanz-Cobena, Garnier, & Vallejo, 2013). Impact of seeds, seedlings, pesticides and fungicides production, as well as manufacture and maintenance of farm's equipment, their transport and their waste management, were omitted in the analysis due to the same contribution on the different fertilization treatments (Meisterling, Samaras, & Schweizer, 2009).

2.5 Data analysis

Data were analyzed using analysis of variance (ANOVA). Means were statistically separated on the basis of Tukey test, when the 'F' test of ANOVA for treatment was significant at least at the 0.05 probability level. Experimental data were processed for a principal component analysis (PCA) using PLS Toolbox software (Eigenvector Research Inc, Wenatchee, WA, USA), in order to evaluate the existing relationships with original variables.

3. RESULTS AND DISCUSSION

During the 3 years of the trial, monthly temperature and rainfall were measured by a weather station in the experimental field. The site was mainly characterized by air temperatures, with minimum values ranging from 10.0 to 12.4 °C and maximum values ranging from 17.2 to 21.8 °C. There was considerable variability in rainfall and its distribution from year to year. The mean annual amounts of rainfall observed over the 3-years, were 670 mm, 990 mm and 360 mm, respectively.

3.1 Aboveground biomass production and its partitioning.

The use of renewable sources as fertilizers could increase the agricultural sustainability. In this point of view, the valorization of agro-industrial byproducts such as organic wastes, may represent an opportunity to reduce the environmental impact related to chemical fertilizer production and use improving soil fertility (Mazzoncini et al., 2015; Zaccardelli, Villecco, Celano, & Scotti, 2013).

Defatted oilseed meals show an interesting economic value as feed for animals, whilst their value as organic nitrogen fertilizers were not fully explored (Mazzoncini et al., 2015) especially for the production of energy crops.

In the present study, results of the analysis of variance for all studied variables showed interesting differences among fertilizers, genotypes and years (Table 3), while no significant interactions were showed among the investigated variables.

At complete maturation of achenes, the main traits influencing the yield component such as number of stalks and heads *per* plant and plant height, were recorded.

Regarding the number of stalks, genotype "Gobbo di Nizza" recoded the higher production +29% respect to "Altilis 41" and, in the first year of cultivation, was recorded the lower production, -41%, compared to the other two years.

The number of heads was affected by fertilizer, genotype and year. N100 recoded the highest value (+46%) compared to the unfertilized treatment. However, the other fertilizers showed similar values to N100, except for DMB3 and N0. "Altilis 41" recorded the higher value (+16%) compared to "Gobbo di Nizza". The first year was the more productive (+18% and +54%) respect to the second and the third ones, respectively.

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

About the most important trait, aboveground biomass, N100 recorded the higher value of stalks and leaves dry weight (+73%) followed by DMS3 (+14%) compared to unfertilized treatment, respectively. Genotype "Altilis 41" showed the higher value (+13%) and, in the first year, was recorded the highest production, +62% and +100%, compared to the second and the third ones, respectively.

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

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

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

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

Finally, regarding the average weight of the heads, no effects were recorded by the different fertilizers. Genotype "Altilis 41" performed better than "Gobbo di Nizza" (+26%) while, in the second year, was recorded the highest value (+5% and +36%) respect to the first and the last ones, respectively.

Summarizing our results, DMS3 could be a sustainable organic fertilizer for the production of cultivated cardoon. Similar results were obtained by Mazzoncini et al. (2015) working on vegetable crops such as lettuce, chard and spinach. The lower agronomical performance of DMB3 was putatively due to the content of glucosinolates that may reduce the availability of nitrogen and/or inhibit the effect on nitrification processes (Mazzoncini et al., 2015).

Zaccardelli et al. (2013) reported a significant positive response of the soil enzymatic activities due to the addition of seed meals for the eggplant production, indicating a beneficial effect on soil quality. In addition, Zaccardelli et al. (2013) showed that defatted oilseed meals, compared to compost, highlighted an increase of soil enzymatic activities only in the first two months after application, reflecting the rate of release of nutrients, such as mineral fertilizers. Hence, the lower release of nutrients showed by compost could be negatively affects the cardoon production in the present work. However, further investigations are required to confirm this hypothesis.

In the preset study, "Altilis 41" performed better than "Gobbo di Nizza", reflecting its suitability for the investigated environment (Acquadro et al., 2012).

About biomass production, the results recorded in the present study are in agreement with Fernández (1998), that reported a biomass production of *C. cardunculus* from 10 to 20 t of d.w. ha^{-1} $year^{-1}$, if the crop is well established and rainfall is about 500 mm $year^{-1}$. Also González et al. (2004) recorded an aerial biomass production (about 11 t ha^{-1} of d. w.) similar to our results.

Moreover, our results regarding biomass production, dry weight distribution, number of heads and plant height, were in agreement with those reported in an interesting study conducted by Ierna & Mauromicale (2010). The authors cropped genotype "Cardo gigante di Romagna" under low input crop management applying 80 kg ha^{-1} of nitrogen as ammonium nitrate.

On the other hand, comparing our results with those obtained under high input management, the maximum yield recorded in the present study was lower (about -50%) respect that one reported by Mantineo et al. (2009) who, however, used a different genotype (Cardo gigante inerme) with high irrigation and fertilizer treatment (irrigation as 75% of evapotraspirated water and fertilization as 100 kg ha^{-1} of nitrogen). Nonetheless, similar to our results, a lower aboveground biomass yield (less than 1 t ha^{-1} of d. w.) in the last year of cultivation was registered.

Cardoon needs less nitrogen than many other crops. In many field experiments, high biomass yields were attainable under fertilization dressings from 0 up to 50 kg of N ha^{-1} (Grammelis et al., 2008). In fact, an interesting point was observed with compost fertilization. In the present study, 30 t ha^{-1}, corresponding to about 600 kg N ha^{-1}, were applied and a biomass production similar to unfertilized treatment was registered.

3.2 Relationships among the recorded parameter, fertilization, genotype and years

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

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

Year 2012 was in the middle between years 2011 and 2013, overlapping in some points. This fact confirms the annual variation showed in Table 3. The yearly variability due to different weather condition, as reported in the present study, was highlighted also in other studies conducted in a similar area (Rinaldi, Convertini, & Elia, 2007; Ronga et al., 2015). Moreover, the differences recoded between the two growing seasons were putatively ascribed at the different weather condition between the three years. In fact, 2013 was drier and colder than 2012 and 2011 (Table 2), probably causing the longest crop cycle (Table 2) and the lowest biomass production (Table 3). In fact, the production of aboveground biomass on *C. cardunculus* depends on the presence of water in the soil, especially in dry conditions and the adequate fertilization of the crop. In experiences carried out in several countries of the Mediterranean zone, was highlighted a high correlation between the rainfall of the year and the total biomass production of cardoon, especially with the rainfall occurred during Spring (González et al., 2004).

3.3 Environmental impact

The GWP of cardoon production *per* area is reported in Figure 3a; the higher impact recorded in the present study was mainly due to GHG emissions to produce fertilizers, followed by direct and indirect emission and, then, by agricultural operations (data not shown). Among treatments, N0 had the lowest impact *per* hectare, followed by N50 and defatted oilseed meals (Figure 3a). On the other hand, the impact *per* total biomass was obviously lower for unfertilized treatment than fertilized ones. In fact, opposite results were observed using 1 t of harvested biomass (d. w.) as FU (Figure 3b). Treatment C30 achieved a higher impact (+230% on the average impact), due to low yield (-10% on the average yield) (Table 3). An interesting result was showed by the impact of defatted oilseed meal of sunflower meal that was lower *per* unit area compared to N100 treatment and remained similar when computed *per* t of harvest d. w., showing about 240 kg CO_2eq *per* t of d. w.

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

Moreover, our results regarding GWP, both per cropped area and crop yield, are comparable with those reported by Cocco et al. (2014) and Razza et al. (2015) who investigated the life cycle assessment of cardoon cropped in Southern Europe and Sardinia and Sicily, respectively.

4. Conclusions

Following 3 years of observation, organic fertilizer cloud be a sustainable approach for the cardoon production in the environment of Southern Italy. Defatted oilseed meal of sunflower may be properly used as organic fertilizers for cardoon production, ensuring yields comparable with those obtained using mineral nitrogen fertilizer. The present study showed the higher efficacy of defatted oilseed meal of sunflower in sustaining aboveground biomass yield when compared to *B. carinata* meal and compost. The GWP of defatted oilseed meal of sunflower was also better than the *B. carinata* meal and compost footprints. Overall, our findings confirmed the high value of oilseed meals as a sustainable alternative to mineral fertilizers and an important nutrient source also for cardoon production. From the agricultural point of view, the success of the application of defatted oilseed meal of sunflower increase the agricultural sustainability. In conclusion, the potential of cardoons as energy crop in Mediterranean cropping systems under sustainable inputs managements is confirmed in terms of aboveground biomass production. However, future research investments are required to increase and optimize yield and GWP of cardoon production.

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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
K_2O (mg/Kg)	324.0
P_2O_5 (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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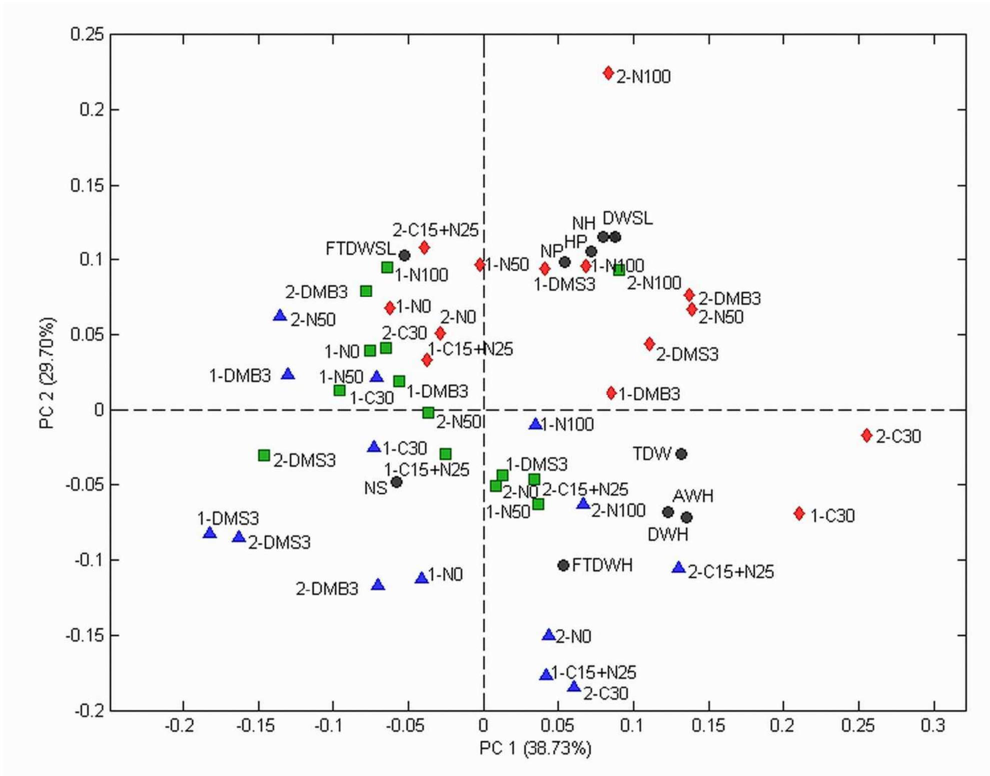

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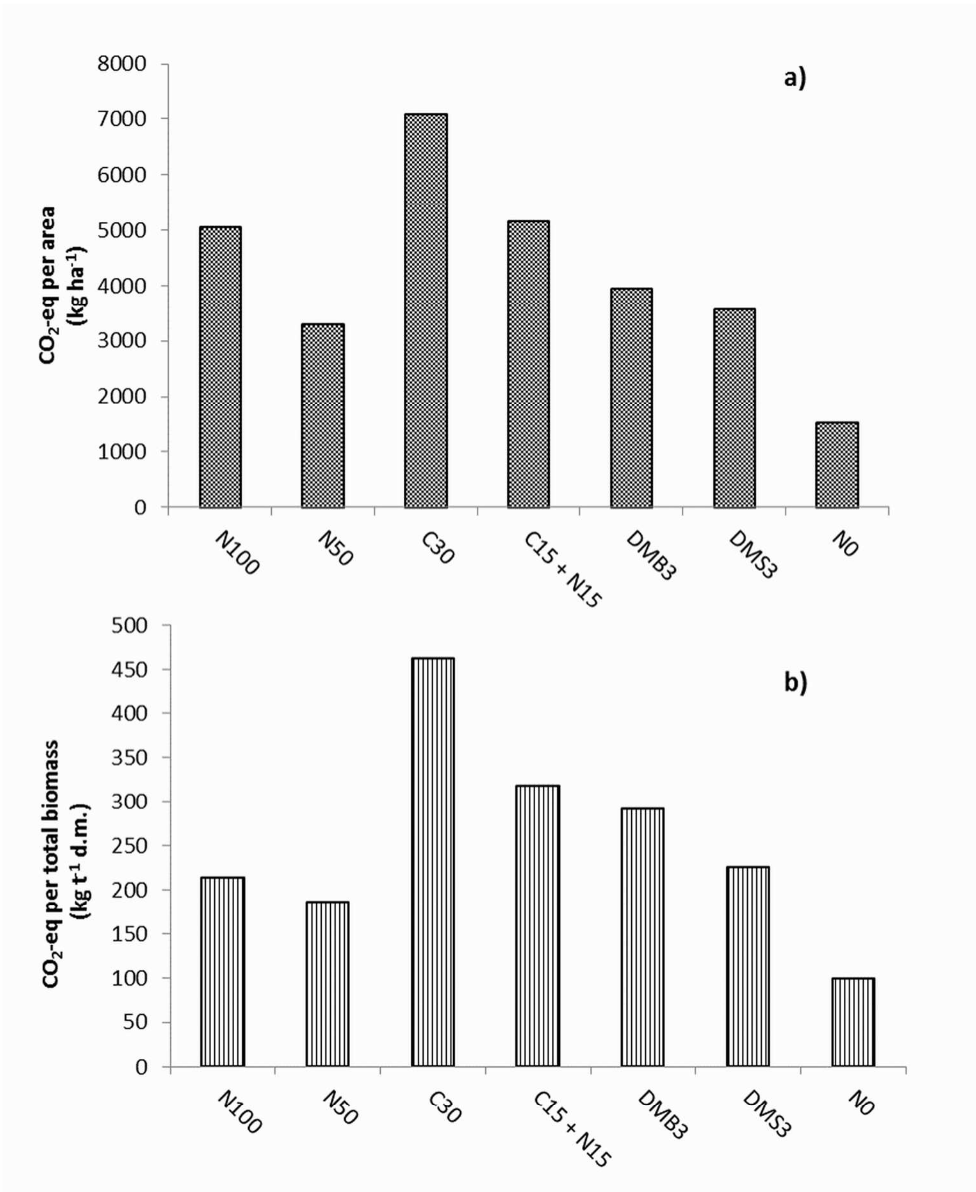

833x1013mm (72 x 72 DPI)

Figure 1. Cardoon growth cycle: vegetative stage (on the left), reproductive stage (on the middle) and harvest stage (on the right).

Figure 2. Ordination biplots of principal component analysis outputs. Labels in the graph indicate the investigated treatments, genotypes and years (red diamonds = 2011, green square = 2012 and blue triangle = 2013) and recorded traits (represented by black circles). 1- = Gobbo di Nizza. 2- = Altilis 41. 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}. NS = numbers of stalks; FTDWH = fraction of total dry weight to heads; DWH = dry weight of heads; AWH = average fresh weights of heads; TWD = total dry weight of plant; FTWDSL = fraction of total dry weight to stalks; NP = number of plants; HP = height of plants; NH = number of heads; DWSL = dry weights of stalks.

Figure 3. Impact on global warming per: (a) area unit (CO_2-eq per hectare); (b) total biomass unit (CO2-eq per kg of total crop aboveground dry matter). Crops were fertilized with 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}.