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Article

Agro-Ecology for Potential Adaptation of Horticultural Systems to Climate Change: Agronomic and Energetic Performance Evaluation

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Abstract: Adaptation can be a key factor that will shape the future severity of climate change impacts on food production. The objective of this study was to assess the suitability of an agro-ecological approach based on various techniques as potential adaptation strategy in organic horticultural systems. A long-term field experiment was set up in Southern Italy, combining: (i) appropriate soil surface shaping; (ii) cash crop rotation; (iii) agro-ecological service crops (ASC) introduction as living mulch and complementary crops; (iv) tailored organic fertilization; and (v) alternative tillage strategies. In this paper, the first two-year results on cauliflower (*Brassica oleracea* L.) and tomato (*Solanum lycopersicum* L.) crops, as well as energy consumptions through the Energy Analysis (EA) method are reported. Due to the climatic conditions that occurred, which were characterized by the absence of extreme climatic events (particularly rainfall), it was not possible to verify if the designed experimental device was able to mitigate the impact of climate change, whereas the EA indicated that total energy inputs were lower when ASC are introduced in cropping systems.

Keywords: agro-ecological service crops; crop rotations; energy analysis; energy productivity; living mulch; organic fertilization; roller crimper

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1. Introduction

Agriculture is highly sensitive to climate variations, which are the dominant source of the overall interannual variability of production in many regions and a continuing source of disruption to ecosystem services [1]. In particular, according to Altieri et al. [2], predicted changes in temperature and increased frequency of extreme events (e.g., droughts and floods) will lead in some areas to reduced crop yields and yield stability, thus likely affecting food security.

Indeed, there are many potential ways to introduce management-level adaptation options for cropping systems, thus dealing with projected climate changes [3–5]. These adaptations include strategies such as altering varieties/species to those with more appropriate vernalization requirements and/or with resistance to heat shock and drought. As a matter of fact, plant breeding could provide later/earlier-maturing hybrids and cultivars, which would be beneficial for crop productivity, due to shorter vegetative growth period under expected climate change. Soil organic matter management and use of technologies to harvest water and conserve soil moisture are other options for adaptation, the last one being related to changes in planting dates especially for spring crops, which could be sown earlier under the climate change scenarios. This could be carried out in order to reduce the yield loss and allowing crops to develop during an earlier period of the year with ample soil water.

Moreover, according to Alexandrov et al. [4], switching from monocultures, which are more vulnerable to pest and diseases, to more diversified agricultural production systems, such as appropriate crop rotation systems, will help farmers to cope with climate variation from year to year. This type of agronomic adaptation can be considered at the farm system level, therefore, in the present study it was considered the most important option. Agricultural biodiversity and knowledge preserved by traditional farming systems as well as the innovation developed by effective research are essential to strengthen the resilience of agro-ecosystems in response to a potential change in the climate. In low input and organic farming systems, proper rotations, agro-ecological service crops (ASC) introduction as buffer zones or break crops, reduced tillage and fertilization management can provide beneficial services to the agro-ecosystems, contributing to weed, pest and diseases management, NO_3^- leaching reduction and improving soil water retention and crop tolerance to drought occurrences [6].

In addition, efficient energy use by the agriculture sector is one of the conditions for sustainable agriculture, because it allows financial savings, fossil resources preservation and air pollution decrease [7], and, for this reason, in a climate change context, energy input-output balance can be a win-win tool to study the efficiency and the environmental impacts of agricultural systems in which adaptation strategies are being used.

The research objectives were, therefore, to assess the agronomic and environmental performance as well as the suitability of a set of agro-ecological techniques (and their best synergistic combination) as potential strategies for organic horticulture adaptation to climate change. Cauliflower and tomato crops were identified as model cash crops of our experimental device, since they are usually grown in the horticultural systems of the area in accordance to an autumn-winter and spring-summer cropping cycle, respectively. Their yield and energetic performances were investigated in the innovative MITIORG long-term experimental device, to get an insight into the overall system performances.

2. Results

2.1. Cash Crops Agronomic Results

Significant main effects of living mulch (LM) sowing time and fertilizer treatments on cauliflower head yield and diameter, as well as significant two-way interactions, were found(Table 1). Also, significant main effects of ASC treatment, fertilizer and ASC termination management on tomato marketable yield and fruit dry matter and significant two-way interactions were found.

Table 1. Analysis of variance for the treatments effect on yield performance in cauliflower and tomato crop.

Treatments	Cauliflower Head Yield	Cauliflower Head Diameter	Tomato Marketable Yield	Tomato Fruit Dry Matter
Living mulch (LM)	***	***	-	-
ASC species (ASC)	-	-	***	**
Fertilizer (FERT)	*	*	***	***
Termination (TERM)	-	-	***	***
LM × FERT	**	*	-	-
ASC × FERT	-	-	***	***
ASC × TERM	-	-	***	***
FERT × TERM	-	-	***	***
ASC × FERT × TERM	-	-	n.s.	n.s.

*, **, ***: Significant at the $p < 0.05$, 0.01 and 0.001, respectively. n.s. = not significant.

The highest cauliflower head yield value was obtained in NMC × AD combination, which was significantly different from all ES × fertilizer treatment interactions and the other interactions with NMC treatment (Table 2). In particular, NMC × AD value was significantly higher by 108% thanES

× MSW. Among fertilizers, the best results were found for AD, which showed head yield values in combination with NMC and CS that were comparable with CS × ORG.

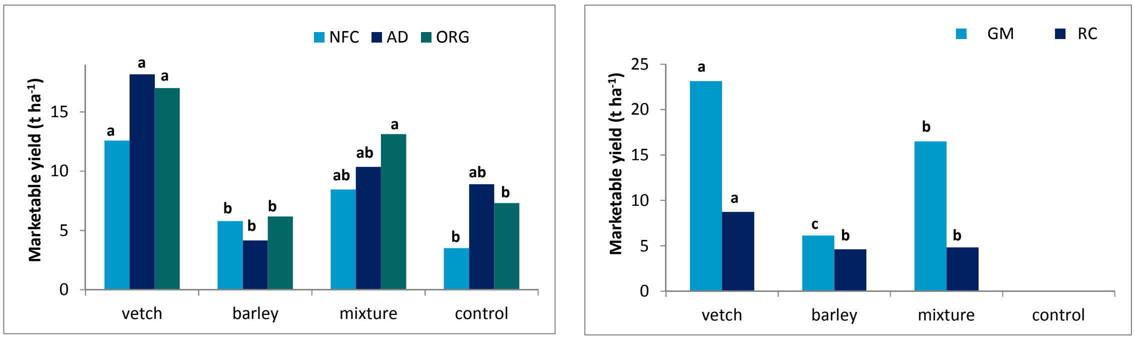
Table 2. Interactions between living mulch (LM) sowing times and fertilizer treatments on cauliflower head yield and head diameter.

Treatment	**Cauliflower Head Yield (t ha^{-1})**				**Head Diameter (cm)**			
	Fertilizer				**Fertilizer**			
Living mulch (LM)	AD [2]	MSW	ORG	NFC	AD	MSW	ORG	NFC
ES [1]	16.1 bd	11.8 d	16.1 bd	14.7 cd	16.6 bd	15.4 d	16.13 cd	15.9 cd
CS	19.4 ac	19.5 ac	21.6 ab	22.4 ab	17.7 ac	17.6 ac	18.4 ab	18.5 ab
NMC	24.7 a	17.6 bd	15.9 bd	17.3 bd	18.9 a	16.8 ad	16.0 cd	17.8 ac

[1] ES: early sowing LM, 20 days before cauliflower transplanting; CS: at cauliflower transplanting; NMC: no LM control; [2] AD: anaerobic digestate fertilizer; MSW: composted municipal solid organic wastes; ORG: commercial humified organic fertilizer; NFC: unfertilized control. Means followed by different letters within raw are significantly different ($p \leq 0.05$ probability level).

The highest head diameter value was obtained by no living mulch control (NMC) × anaerobic digestate (AD) combination (Table 2), whereas the lowest one was determined by early sowing LM (ES) × composted municipal solid organic wastes (MSW), which was not significantly different both from all the ES × fertilizer combinations and NMC × commercial humified organic fertilizer (ORG). Moreover, concurrent sowing LM (CS) significantly increased head diameter on average by 12.5% than ES treatment.

In Figure 1, effects by fertilizers (a) and termination methods (b) of ASC treatments (vetch, barley, mixture and control) on tomato marketable yield are reported.



(**a**) (**b**)

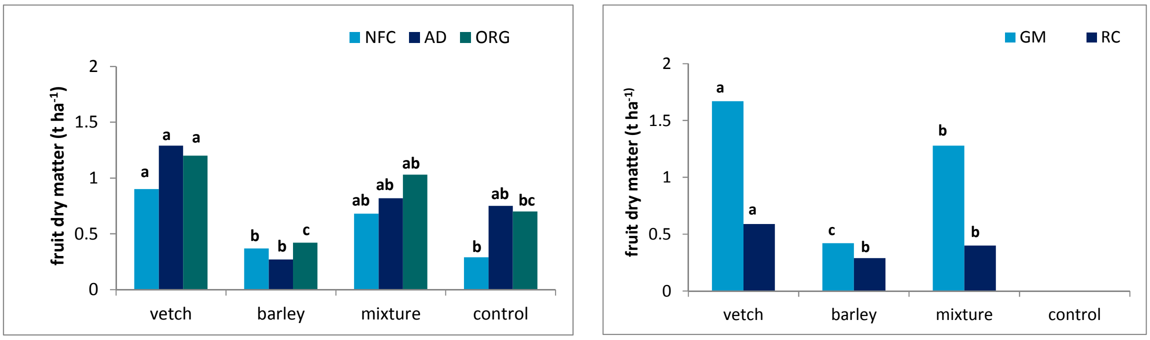
Figure 1. Effects by fertilizers (**a**) and termination methods (**b**) of Agro-ecological Service Crops treatments (vetch, barley, mixture and control) on tomato marketable yield (t ha^{-1}). AD: anaerobic digestate fertilizer; ORG: commercial humified organic fertilizer; NFC: unfertilized control; GM: green manure by incorporating ASC biomass into soil; RC: no till and ASC flattening by roller crimper.

As regards fertilizer effect, AD fertilization determined the significantly highest value in vetch plot and the lowest in barley, whereas the ASC mixture and the control had comparable and intermediate marketable yield values (Figure 1a). The ORG fertilizer determined the highest marketable yield in vetch and ASC mixture, which were higher on average by 144% and 106% than the combination with barley and control, respectively. Best results were obtained in the vetch ASC by NFC treatment, which was not significantly different from the value for mixture, whereas the lowest values were obtained by barley and the double control. On the whole, the green manure (GM) treatment determined higher marketable yield results than roller crimper (RC) treatment. The GM termination method showed the highest value in vetch, the lowest in barley and intermediate value in the mixture (Figure 1b).

Conversely, the RC determined the best result with vetch, being the marketable yield higher by 89% and 81% than the combination with barley and the mixture, respectively.

In Figure 2, effects by fertilizers (a) and termination methods (b) of ASC treatments (vetch, barley, mixture and control) on tomato fruit dry matter are reported.

As regards fertilizer effect, fruit dry matter results were similar to those of marketable yield (Figure 2a), except for ORG, which determined the highest value in vetch plots, which was comparable to mixture value and higher by 185% and 71% as compared to the dry matter in barley and control plots, respectively. Dry matter results by termination methods were perfectly comparable to marketable yield ones (Figure 2b).



(**a**) (**b**)

Figure 2. Effects by fertilizers (**a**) and termination methods (**b**) of Agro-ecological Service Crops treatments (vetch, barley, mixture and control) on tomato fruit dry matter (t ha^{-1}) (AD: anaerobic digestate fertilizer; ORG: commercial humified organic fertilizer; NFC: unfertilized control; GM: green manure by incorporating ASC biomass into soil; RC: no till and ASC flattening by roller crimper.

2.2. Cropping Systems Energetic Performance

The energy analysis showed that the LM treatments (ES and CS) consumed low energy inputs per hectare than the NMC in cauliflower production (Table 3), whereas GM termination consumed more energy inputs than RC management in tomato production.

Table 3. Amounts of each energy input and output, total inputs and production outputs, energy productivity and energy inputs divided by categories, both in cauliflower and tomato cropping cycles (MJ ha^{-1}).

Cauliflower Crop				**Tomato Crop**			
	ES [1]	**CS**	**NMC**		**GM** [2]	**RC**	**CT**
Human labor	387	504	483	Human labor	542	299	303
Machinery	255	255	238	Machinery	504	510	238.2
Fuels	2148	1735	1736	Fuels	4077	2970	1981
Fertilizers	11,461	11,461	22,922	Fertilizers	8595	8595	17,191
Chemicals	180	180	180	Chemicals	480	480	480
Water	428	428	428	Water	1734	1734	1734
Seeds	30	30	0	Seeds	140	140	0
Total inputs	14,889	14,594	25,988	Total inputs	16,074	14,729	21,928
Outputs	24,990	35,190	33,490	Outputs	16,960	6992	7584
Energy Productivity	1.68	2.41	1.29	Energy productivity	1.06	0.47	0.35
Renewable energy	12,306	12,423	23,834	Renewable	11,012	10,769	19,229
Non-renewable energy	2583	2171	2154	Non-renewable energy	5062	3960	2699
Direct energy	2535	2239	2219	Direct energy	4620	3269	2284
Indirect energy	12,354	12,354	23,768	Indirect energy	11,454	11,460	19,644

[1] ES: early sowing LM, 20 days before cauliflower transplanting; CS: at cauliflower transplanting; NMC: no LM control; [2] GM: green manure by incorporating ASC biomass into soil; RC: no till and ASC flattening by roller crimper; CT: fallow-control.

The highest energy consuming input was fertilizer (on average, 82% and 65% for cauliflower and tomato, respectively), followed by fuels (10% and 17% for cauliflower and tomato, respectively) and water (10% for tomato).

In cauliflower, 88% on average of total energy input resulted from renewable as compared to 12% from non-renewable energy, as well as 12% derived from direct and 87% from indirect energy inputs. In tomato, 78% of total energy input resulted from renewable as compared to 22% from non-renewable energy, and 19% derived from direct and 80% from indirect energy inputs.

As regards the amount of energy productivity, in cauliflower production this parameter was higher for CS than both ES (43%) and NMC (86%) treatments. In tomato crop, energy productivity was higher for GM than RC (125%) and fallow-control (CT) (203%). Moreover, on the whole, the parameter was lower in tomato than in cauliflower crop.

As regards the energy consumption for each crop operation done (Table 4), fertilization was the most energy consuming and impacting phase in both analyzed systems. Moreover, in cauliflower soil preparation operations consumed a consistent rate of energy, as well as GM operations and irrigation in tomato crop.

Table 4. Amounts of energy inputs (MJ ha^{-1}) in cauliflower and tomato production divided by crop management operations.

Cauliflower				**Tomato**			
	Operations				**Operations**		
	ES [1]	**CS**	**NMC**		**GM** [2]	**RC**	**CT**
Soil hydraulic arrangement	503	503	503	Soil hydraulic arrangement	503	503	503
Tillage	589	589	589	Tillage	589	589	589
Seedbed preparation	574	574	574	Seedbed preparation	574	574	574
Sowing	90	90	42	Sowing	200	200	0
ASC/weeds mowing	126	126	126	ASC flattering	0	562	0
Planting	78	78	78	Strip tillage for transplanting	0	650	0
Spraying	444	235	235	ASC biomass chopped	1468	0	0
Irrigation	481	481	481	ASC plowed into the soil	846	0	0
Fertilization	11,718	11,515	22,976	Planting	97	97	97
Harvest	287	404	384	Irrigation	1786	1786	1786
				Fertilization	8853	8853	17449
				Spraying	744	744	744
				Harvest	413	170	185

[1] ES: early sowing LM, 20 days before cauliflower transplanting; CS: at cauliflower transplanting; NMC: no LM control; [2] GM: green manure by incorporating ASC biomass into soil; RC: no till and ASC flattening by roller crimper; CT: fallow-control.

3. Discussion

3.1. Cauliflower and Tomato Agronomic Performance

In the MITIORG long-term experimental device, soil surface shaping was carried out to increase rooting depth layer, allowing crop survival in the event of flooding, and to make easier the lateral outflow of excess water. This technique was combined with soil organic matter management, by using organic fertilizers and amendments, that improves soil's water retention capacity and infiltration [8], and farming system diversification to provide agro-ecological services. In particular, on the top of two of the three planned soil convex strips, a leguminous ASC was intercropped as LM with the winter cash crop (cauliflower), in comparison with a no-living mulch control on the third strip. Time of sowing of the ASC, in respect to the transplanting of the cash crop, may determine the effectiveness of this technique in providing agro-ecosystem services [9]. In addition, in the concave soil strips the ASC cultivated in the winter period, as break crops between two consecutive summer cash crops, need to be terminated before cash crop transplanting to avoid competition. Therefore, according to Montemurro et al. [10], to allow the provision of agro-ecological services, ASC are incorporated into the soil by using the traditional green manure method [11], or can be flattened by the innovative roller crimper technique [12].

Although due to the absence of extreme rain events during the trial, which are not completely predictable, it was not possible to verify the effects on climate change adaptation of these combined agro-ecological practices, it was possible to test the agronomic and energy performance of the crop rotation in the innovative experimental device. Cauliflower production and quality (head yield and head diameter) were better with CS than ES (Table 2), in agreement with Kolota and Adamczewska-Sowińska's [13] results, indicating the role of LM sowing period. This result also suggests that no competition was determined by ASC in CS treatment. The comparable yield results of AD and ORG (in combination with both ES and CS), indicated that both are viable options for organic farmers, in agreement with other studies in Mediterranean area [14,15].

Similarly, as regards tomato crop, AD determined comparable results with commercial fertilizer for both marketable yield and fruit dry matter (Figures 1a and 2a). However, for tomato crops, the combination of AD with barley had a marketable yield lower by 77% in comparison with vetch, maybe because of competitiveness of ASC with the vegetable cash crop. This explanation is further supported by considering that a higher absolute value in the AD × control combination was found. In the absence of fertilization, particularly in the double control (no ASC—no fertilizer) the yield performance was very low, indicating that this option of management is not sustainable. Fruit dry matter had on the whole similar results than marketable yield, suggesting poor effectiveness of the combination of fertilizer with barley ASC.

The GM results both for tomato marketable yield and fruit dry matter (Figures 1b and 2b), being higher than RC, confirmed other studies [16]. This is likely because of higher availability in GM of total N by decomposition of aboveground biomass in soil, unlike RC treatment that can readily supply only a small part of the N contained in the leguminous ASC. In fact, the GM termination method showed the highest value in vetch and ASC mixture.

3.2. Energy Analysis Evaluation

Regarding the energy analysis, the most energy consuming inputs were fertilizers, fuels and water (Table 3), in agreement with others studies [17–19]. In addition, fertilization was the most impacting phase in both analyzed systems (Table 4). The great reduction of total energy inputs that was detected in ES and CS in comparison with NMC for cauliflower, and in GM and RC as compared to CT for tomato, would indicate that leguminous ASC can be useful not only in providing agro-ecological services [20,21], but also in maintaining cropping system sustainability. In fact, the energy productivity was higher in ASC treatments than in control ones, as well as CS seemed to be the best solution likely due to the reduction of ASC competitiveness with the cash crop. The energy productivity results also suggest that GM termination was more efficient than RC in tomato crop.

In general, under the experimental conditions of our study, the energy consumption in the innovative organic horticultural system managed with agro-ecological practices was lower than the energy used in conventional systems founded in literature [18].

The synergistic combination of hydraulic arrangement, conservation tillage and ASC introduction and management can help farmers to increase energy use efficiency by decreasing energy consumption and sustaining crop yield.

In conclusion, combined application of agro-ecological techniques is a viable strategy, sustaining yield of cash crops in rotation, and helping in adaptation of horticultural systems to the climate changes. This is due to a reduction of energy consumption (and consequently of GHG emissions) and increase of energy productivity.

However, the study period could not be sufficient to draw general conclusions, therefore, more data will be analyzed in this ongoing research to validate the reported preliminary results.

4. Materials and Methods

4.1. Study Site and Experimental Device

The study has been conducted in the innovative MITIORG organic field experiment (*Long-term climatic change adaptation in organic farming: synergistic combination of hydraulic arrangement, crop rotations, agro-ecological service crops and agronomic techniques*) on the research farm 'Azienda Sperimentale Metaponto' of the Research Centre for Agriculture and Environment, Council for Agricultural Research and Economics (CREA-AA) (lat. 40°24′ N; long. 16°48′ E).

Soils are classified as Typic Epiaquerts [22]. The climate is classified as "accentuated thermomediterranean" according to the UNESCO-FAO soil classification system [23], with mean monthly temperatures of 8.8 °C in the winter and 24.4 °C in the summer. The site is generally characterized by winter temperatures which can fall below 0 °C, and summer temperatures which can rise above 40 °C.

During the cauliflower cropping cycle, over the period August-December 2014, total rainfall was lower than the 30-year long-term average (221 mm and 267 mm, respectively). A single peak was reached at the beginning of October with 63 mm of rainfall in 24 h. Mean temperature was higher (18.6 °C) than the long-term average (17.1 °C).

Conversely, during tomato cropping cycle (April-August 2015 period), both the total rainfall (116 mm) and mean temperature (21.8 °C) were very close to the 30-year long-term averages(117 mm and 20.8 °C, respectively).

The field experiment was designed combining a suite of functionally integrated techniques (conceptually identified as "layers"), namely: (i) soil surface shaping; (ii) crop rotations; (iii) ASC introduction; iv) ASC termination techniques; and (v) organic fertilization.

The base layer is the soil hydraulic arrangement by means of soil surface shaping as a kind of ridge system. Vegetable crops are cultivated both above the raised bed (*ridges* 2.5 m wide) and in the 2.5 m flat area (or *strips*) between them. Rotation (the second conceptual layer) is designed to avoid cash crops cultivation during the winter-rainy period of the year in the flat strips, which can be waterlogged in the case of heavy rain and/or temporary flooding, as frequently have occurred in the area in the last years. Moreover, in order to protect the soil from erosion and provide N to the system *via* biological fixation, a next conceptual layer based on tailored introduction of ASC is implemented. On the top of the ridges, a leguminous ASC (burr medic, *Medicago polymorpha* L.) is living mulched (LM) in the winter vegetable crop and maintained as a living ground cover throughout its cycle, controlling time by time its growth by mowing. In the flat soil strips, pure ASC or mixtures of different proportions of legume and non-legume crops, potentially resistant to temporary water excess, are cultivated in the winter-rainy period as break crops. The break ASC in the furrow strips are terminated by the no-till roller crimper technique, before the transplant of the next summer cash crops. The last layer consists of an organic fertilization strategy, which is implemented by using commercial and/or novel fertilizers and amendments, to maintain or increase long-term soil organic matter and fertility.

4.2. Experimental Setup and Treatments

The research here reported was carried out during the 2014–2015 season comparing winter cauliflower (*Brassica oleracea* L. cv. Triunphan) cultivated on the ridges with different management variant of the legume LM, and tomato (*Solanum lycopersicum* L. cv. Donald) cultivated in the furrow strips after different composition variant of the break ASC. In more detail, the cauliflower experiment was carried out according to a strip-plot design, where two factors and three replications were tested [24]. The first factor was LM management comparing three treatments: (i) early sowing LM (ES; 20 days before cauliflower transplanting); (ii) concurrent sowing LM (CS; at cauliflower transplanting) and (iii) no living mulch control (NMC). Each main plot was divided, as a randomized complete block design, into four sub-plots to test the second factor corresponding to the following organic fertilizers (F), allowed in organic farming [25]: (i) local anaerobic digestate fertilizer, based on cattle slurry (AD); (ii) composted municipal solid organic wastes (MSW; *Fertileva*-Progeva s.r.l., Laterza, TA, Italy); (iii) commercial humified organic fertilizer (ORG), based on dried cattle manure (Italpollina; CRAI s.r.l., Rivoli Veronese, VR, Italy); all compared to (iv) an unfertilized control (NFC). The organic materials were applied to soil one month before cauliflower transplanting, at 100 kg N ha^{-1} rate. The fertilization applied in ES and CS was compared to an application rate of 200 kg N ha^{-1} in the NMC plots, considering the potential contribution of LM biological N fixation in the first two treatments. Each LM sowing times × fertilizer plot (intersection plot) resulted in a 24 m^2 area. The cauliflower was manually transplanted on 2 September 2014(1 × 0.60 m; 17,000 plants ha^{-1}) and it was harvested four times at commercial maturity, from 28 November to 3 December 2014.

As regards tomato crop, the experiment was carried out according to strip-split-plot design where three factors were tested. The ASC composition was the first factor and vetch (*Vicia sativa* L.), barley (*Hordeum vulgare* L.) and a mixture of them were cultivated in the winter period, before cash crop transplanting (compared to a no-ASC control; NAC). The second factor was the soil tillage-ASC termination technique and the following variants were tested: (i) tillage/ASC green manure obtained incorporating into soil the ASC biomass by rotary hoe (to a 15–20 cm in depth) at the end of ASC flowering (GM); (ii) no till and ASC flattening by roller crimper (RC), in which the obtained thick mulch layer remained in place covering the soil surface and, after tomato harvest, it was incorporated in the soil by rotary tiller (15 cm in depth). These treatments were compared to (iii) a fallow-control, in which ASC was not sown (CT). The third factor was the organic fertilization and the following treatments were compared: (i) AD; (ii) ORG; compared to (iii) NFC. The organic materials were applied four days before ASC termination, at the rate of 75 kg N ha^{-1}. To account for the potential contribution of ASC for N, the fertilization applied in AD and ORG was compared to an application rate of 150 kg N ha^{-1} in the NAC. Each intersection plot resulted in a 30 m^2 area. Tomato crop was manually transplanted on 27 April 2015 (1 × 0.40 m; 25,000 plants ha^{-1}) and it was harvested three times at the crop commercial maturity, from 14 July to 26 August 2015.

4.3. Crop Measurements and Statistical Analysis

Cauliflower heads were collected from three randomly selected plants in each plot during the cash crop harvest and head yield (t ha^{-1}) and head diameter (cm) were determined. Similarly, tomato marketable yield (t ha^{-1}) was obtained from three randomly selected plants in each plot, by collecting marketable red fruits. Fruit dry matter (t ha^{-1}) was also determined after measuring fruit dry weight at 70 °C for 48 h.

Analysis of variance (ANOVA) was carried out, with ASC management strategies and cultivar/fertilizer as factors. To compare the differences obtained, means were further analyzed by Tukey HSD test and SNK test ($p < 0.05$) for cauliflower and tomato, respectively.

4.4. Energy Analysis

To assess the environmental impact of introduction of the above-described agro-ecological strategies, an Energy Analysis (EA) was carried out. Effects of energy input on cauliflower and tomato crops management were determined according to the Namdari et al. [26] methodology. Total energy inputs and outputs for production unit (hectare), reported in MJ, were established by multiplying each input with its own coefficient of equivalent energy as specified in Table 5. The energy equivalents per unit were found in the literature [18,27,28].

Moreover, 'energy productivity' parameter was calculated by means of the following formula by Mohammadi et al. [29]:

$$\text{Energy ratio} = \text{Energy output (MJ ha}^{-1}\text{)/Energy input (MJ ha}^{-1}\text{)} \quad (1)$$

The energy inputs were further identified as direct and indirect intakes. They were also divided into renewable and non-renewable energy categories [30]. In particular, both human labor and fossil fuels were considered as direct energy, whereas seeds, water, chemicals, fertilizers and machinery were accounted for as indirect energy. Renewable energy consisted of human labor, seeds, water and organic fertilizers, and non-renewable energy was represented by machinery, fuels and chemicals. The EA was used for the living mulch strategy and different ASC management, whereas the fertilization strategies were not analyzed because only the balance for total N, P_2O_5 and K_2O amounts was determined.

Table 5. Energy equivalents of each input and output for the agricultural production, according to [18,27,28].

Input	Unit	Energy Equivalent (MJ unit^{-1})
Human labor	h	1.96
Machinery	kg	80.0
Fuels		
diesel	kg	46.2
lubricant	kg	78.1
Fertilizers		
N	kg	66.1
P_2O_5	kg	12.4
K_2O	kg	11.1
Chemicals	kg	120
Irrigation water	m^3	1.02
Seeds	kg	1.00
Output		
Cauliflower	kg	1.70
Tomato	kg	0.80

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