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Working Paper N. 15/2018

DISEI, Università degli Studi di Firenze
Via delle Pandette 9, 50127 Firenze, Italia
www.disei.unifi.it

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Summary

Urban population growth has raised concerns about food security. Agricultural systems are asked to satisfy a growing demand of food while addressing sustainability issues and facing resource constraints. Ecological footprints are a widespread instrument for the study of human dependence on natural resources. Among these tools, Land Food Footprint (LFF) is used to measure the land actually used to produce the food needed to satisfy the demand of a specific region or country. Understanding the differences between alternative production methods and the gaps between available and needed land is crucial in order to integrate food security and sustainability into rural development programmes and urban planning. The objective of this study is to analyse the Land Food Footprint of Tuscany (Italy) both for organic and conventional production methods, taking into account the nexus of diet. In this aim, we assess Land Food Footprint for the considered production processes under four different diet scenarios with different levels of animal protein consumption. The study shows that the gap between organic and conventional land requirements varies considerably between vegetable and animal foods. It confirms that organic agriculture needs more land than conventional one, but the gap between land footprints shrinks as consequence of dietary changes. The most important finding is that, in the case study, organic agriculture could feed the population if the diet shifts towards reduced intake of animal protein. In fact with a 50% diet reduction in animal proteins, the organic land food footprint value is equal to the conventional land food footprint under the status quo scenario.

Keywords: sustainable food system, land food footprint, diet nexus, organic agriculture, food security

INTRODUCTION

The world's urban population has grown rapidly. The population in urban settlement has shifted from the 746 million of 1950 to the 3,9 billion of 2014, reaching the 53% of the total population. In 2017, 69% of Italian population lives in urban areas (World Bank, 2018). World's concerns about run-away population growth have raised the debate about natural resource carrying capacity for human life. People migration, from the country to the cities, drives urban expansion into agricultural area with loss of cultivated land. The main consequences of such phenomena, at local level, are increasing urban food demand and reduction in bio productive land. In fact, population concentred in urban settles are net food buyers demanding food supplied by local agriculture, rural areas or by food imports. These consequences set in motion a vicious cycle in which abandon of rural areas and reduction of agricultural cultivated land are tied with growing urban demand of food at declining prices up to levels to which local agricultural cannot compete, resulting both in farms exit and in agricultural intensification. This process increases food dependency on the global food market, on fossil fuel and on intensive farming. As a consequence there is the need to face scarcity of life-sustain natural resources, sustainability and food security issues shedding light on organic agriculture viability (Muller et al., 2017). In this respect land footprint is an useful instrument to assess "the land used to produce the goods and services devoted to satisfy the domestic final demand of a country regardless of the country where this land was actually used" (Arto et al., 2012). The Land Food Footprint is the quantification of the per capita agricultural utilised area (AUA) amount needed to feed the local population, essential in order to integrate food security into sustainable agriculture objectives. According to the World Bank (2014b) the value of Arable Land per Person in Europe is equal to 0,2 hectare, while in Italy is equal to 0,1 hectare per person. Taking into account different dietary patterns in considering organic (OA) and conventional agriculture (CA) can promote specific measure for achieving sustainability both in the supply and demand side of the food system.

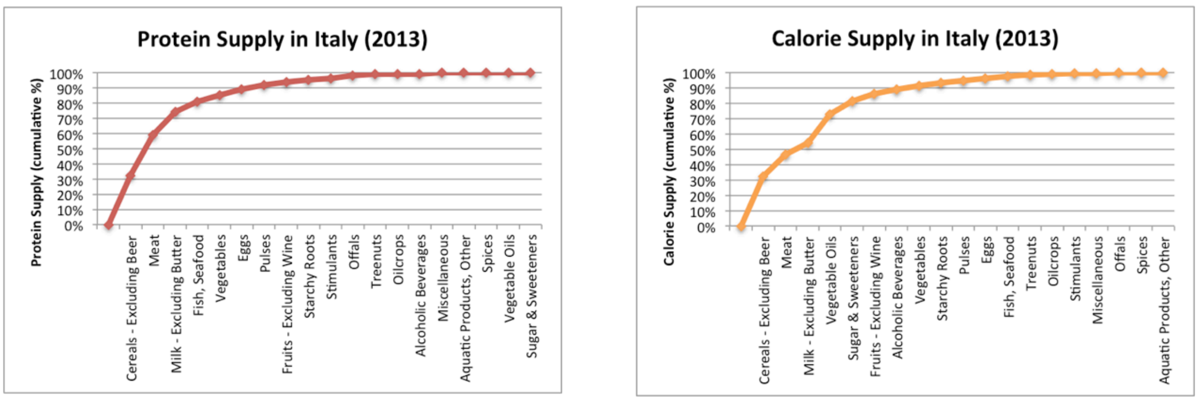
The purpose of this study is to assess how much land OA and CA need to satisfy the food demand of the local population taking into account the nexus of diet. In this aim, we conduct our research in the case study of Tuscany (Italy). Tuscany accounts for 3.742.437 inhabitants with approximately 0,2 hectare of Agricultural Utilised Area (AUA) per capita. Our research demand is: i) what would be the impact of farming systems transition toward OA in terms of agricultural land availability and ii) shifts in the dietary habits could reduce the gap between OA and CA land food footprint? We quantify bread, pasta, milk and meat LFF taking into account the per capita consumption. These key products are the main source of protein and caloric intake for the local population. Additionally, they play an important role on farm management and sustainability at farm level. We assess land food footprint for organic and conventional production processes under three different scenarios: i) "status quo", based on the Italian average per capita consumption of the selected foods; ii) "diet change", based on a reduced trade-off between animal and vegetable proteins with 50% less of animal protein consumption; iii) "closed loop farming" assuming rotation patterns as a diet constraint; iv) "vegan diet" with only vegetable proteins. The paper is structured as follows: section 2 describes the approach employed to assess land food footprint and data sources; section 3 presents results and discussion; concluding remarks are shown in section 4.

MATERIALS AND METHODS

In the new global economy, Ecological Footprints (EF) have become a key instrument for the study of human dependence in natural resources (Ferng, 2011). This issue has grown in importance considering the increasing human population, the scarcity of renewable natural resources and, consequently, the dramatic importance of the principles underpinning sustainable development. The concept of ecological footprints has been introduced in 1994 by Rees and Wackernagel who measured "how much land/water, wherever it may be located, is required to produce the resource flows (consumption) currently enjoyed by that region's population" (Rees and Wackernagel, 1996). Parallel to the interest in scientific literature on EF, another line of research has focused on those consumption-indicators such as carbon footprint, water footprint, land footprint and material footprint which measure resources use indicating the environmental pressures and the global implications related to the consumption levels of the resource (O'Brien et al., 2015). In this paper, we adopt a land footprint approach to assess the food system sustainability. As stressed by O'Brien et al. (2015) it is necessary to distinguish between the ecological footprint and land footprint. In particular, while ecological footprint theoretically measures the land area used/needed to supply resource consumption and absorb emission, land footprint represents the actual "land used to produce the goods and services devoted to satisfy the domestic final demand of a country" (Arto et al., 2012). According to O'Brien et al. (2015) and Bruckner et al. (2014) land footprint, as a metric to asses actual land needed to meet specific good demand, is only recently widely implemented using biophysical, economic or hybrid accounting methods. In particular, the biophysical approach assesses the Land Food Footprint (LFF) on the basis of land productivity expressed by yield (tonnes per hectare) or by a conversion rate, providing the amount of a given crop land needed to obtain one unit (kg) of the consumed food (meat, milk etc.). The economic approach accounts the land footprint as different monetary values of the products obtained by the harvest of each considered hectare. The hybrid methods combine the biophysical and the economic approach. The land footprint approach is used to assess differences in land availability and land demands at different scale. LFF is accounted to investigate the change of land footprint over time

(Bosire et al., 2015; de Ruiter et al., 2017; Kastner et al., 2012) and the differences between land availability and demand (land flows) to assess land use sustainability and inequality between regions or countries. Moreover, the local food systems conservation is increasingly recognized as a key factor in the pursuit of sustainable and resilient settlement systems, dealing with reallocation of energy and materials flows in a 'circular' economy perspective. Many studies (Alexander et al., 2015; de Ruiter et al., 2017) provide an evaluation of land food footprint with a top-down approach based on the agricultural land use and its productivity in terms of capacity of supplying food. We adopt a bottom-up methodology based on assessment of the land food footprint of the per capita consumption of meat, milk, pasta and bread, applying a demand side approach instead of a supply side approach. Consumption data sources are ASSOCARNI for meat (ASSOCARNI, 2015), FAO for milk (FAOSTAT, 2014a), ISMEA for pasta (ISMEA, 2014) and Coldiretti for bread (Coldiretti, 2015). We select these food typologies since they embody the major food group in local diet. According to de Boer et al. (2006) "meat, cereals and milk provide the main part of European dietary proteins". In particular, in 2013, in Italy, meat, cereals and milk provided the 74% of the total protein intake (FAOSTAT, 2014b) and the 54% of the total calorie intake (FAOSTAT, 2014c) (Figure 1) of the Italian diet. In addition, livestock and wheat constitute the two main agricultural production systems.

Fig. 1 Protein and calories supply in Italy

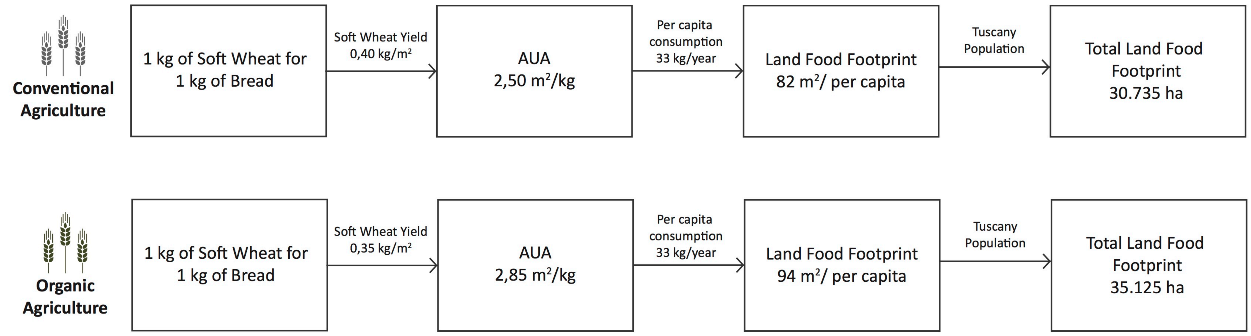


Source: FAOSTAT, 2014b

Source: FAOSTAT, 2014c

We use data on regional yield of organic and conventional crops, then we apply a food and feed conversion rate to assess the amount of agricultural land needed to supply one kilo of each consumed food type. We also account the conversion rate of raw materials into edible products through the primary (e.g. milling) and secondary processing (e.g. baking). An example of the land food footprint approach adopted is provided in Figure 2.

Fig. 2 Example of Land Food Footprint assessment (organic and conventional soft wheat)



Source: own elaboration

We consider all the agriculture production cycle for each key food category including crops rotation as well as all the necessary inputs to produce meat and milk, taking into account the full animal chain from cow breeding to calf. We do not consider food waste since it is included in the consumption values. Specifically, we assign the agricultural area necessary to produce one kilo of a cereal product according to the following equation (1):

$$area_i = \frac{FCR_i}{yield_i} \qquad (1)$$

where FCR_i and $yield_i$ are, respectively, the food conversion rate and yield for crop i. Area for livestock products was computed through a slightly different equation (2) which allows us to consider all h ingredients composing the diet of livestock product i:

$$area_i = \sum_{i=1}^{k} \sum_{j=1}^{h} \left(FCR_i \times \frac{crop\ requirement_j}{yield_j} \right) \qquad (2)$$

where $area_i$ is expressed as the summation of areas needed to feed the animal i with the h types of crop required for its diet, considering both the yield of crop j and a specific feed to food conversion[1] for livestock product i. Then, we calculate land food footprint for the generic item i (LFF_i) as in (3):

$$LFF_i = area_i * consumption_i \qquad (3)$$

Land Food Footprint per capita (LFF_{pc}) is finally computed as the summation of the land food footprint for the k considered items:

$$LFF_{pc} = \sum_{i=1}^{k} LFF_i \qquad (4)$$

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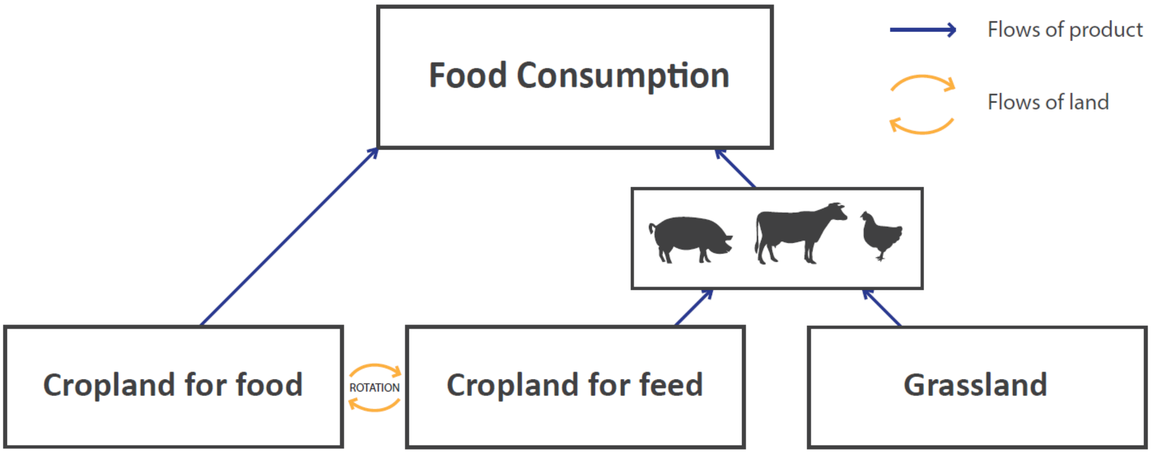
[1]Species, genotype and type of production involve different feed requirements and rearing system but also different performance variables (e.g. fertility, fecundity rate, productivity). Therefore, for each rearing category and system we assume several parameters, such as: feed per day, average daily gain, slaughter weight, slaughter age and slaughter yield.

To model the rotation pattern we consider three different land uses according to the regional rotation pattern and agricultural practices (Figure 3). In the rotation pattern, we simulate two different patterns for organic and conventional agricultural practises (Figure 4). We also assume an agricultural management orientation in which wheat is in rotation with feed. In this situation the land utilised for feed purpose, supplying the meat or milk production systems, is accounted in protein production (meat and milk) reducing the amount of LFF for the wheat production.

Fig. 3 Land Use Categories



Source: own elaboration

Then, we consider four scenarios: i) "status quo", based on the Italian average per capita consumption of the selected food items; ii) "diet change", with a 50% reduction in animal protein consumption; iii) "closed loop farming" assuming rotation patterns as a diet constraint; iv) "vegan diet" with only vegetable proteins. Some studies and institutions (e.g. FAO and the Chinese Government) underline the need to reduce meat consumption (Bryngelsson et al., 2016; Westhoek et al., 2014; FCNR, 2018; Milman and Leavenworth, 2016).

Fig. 4 Rotation patterns

Conventional					
Year	I	II	III	IV	V
Crop	Wheat	Feed	Wheat	Feed	Wheat
Year	VI	VII	VIII	I	II
Crop	Feed	Wheat	Feed	Wheat	Feed

Organic					
Year	I	II	III	IV	V
Crop	Wheat	Feed	Wheat	Feed	Wheat
Year	VI	VII	VIII	IX	X
Crop	Feed	Wheat	Feed	Feed	Feed

Source: own elaboration

We convert the amount of meat and milk consumption in protein supply, considering, for each food stuff, the protein content provided by the USDA (United States Department of Agriculture) Food Composition Databases (USDA, 2018). Then, in each scenario, we assume to substitute the meat protein intake with an equivalent amount of proteins provided by vegetable food such as peas, chickpeas, lentils and beans. The obtained regional land food footprints for each scenario and for OA and CA methods were then compared each other and with the Tuscany available land (AUA), split into the different available land uses to evaluate the regional land balance.

RESULTS

In Tuscany for the first scenario ("status quo scenario"), considering regional LFF for the selected food typologies and regional AUA (ISTAT, 2010), some differences arise in terms of land balance and in terms of gap between OA and CA (Table 1 and 2). OA needs in total 34% more land than CA (Table 2). The regional LFF for OA is 1.034.756 ha, requiring almost four times the regional AUA for the considered land typologies (260.149 ha), while CA accounts for a land unbalance of 420.417 ha. Considering land use the picture is different and it varies with respect to each food category.

Table 1. Land Food Footprint for conventional agriculture

Conventional Agriculture								
	Per capita consumption (Kg)	LFF (ha/per capita)	Relative Impact of products	Protein supply quantity related to daily protein intake	Calorie supply quantity related to daily calorie intake	Total LFF (ha)	Total AUA in Tuscany for category	Gap between AUA and LFF
Beef	19,3	0,0527	29%	10%	3%	197.185		
Pork	37,3	0,0477	26%	15%	8%	178.679		
Poultry	18,9	0,0176	10%	8%	2%	65.781		
Total Meat	75,5	0,1180	65%	33%	13%	441.645		
Milk and diary	260	0,0442	24%	21%	10%	165.416		
Total Meat and Milk	**335,5**	**0,1622**	**89%**	**54%**	**23%**	**607.061**	**137.879**	**-469.182**
Bread (Soft wheat)	32,85	0,0082	5%	9%	7%	30.735	19.419	-11.316
Pasta (Durum wheat)	24	0,0114	6%	8%	7%	42.771	102.851	60.080
Total Bread and Pasta	**56,85**	**0,0196**	**11%**	**16%**	**13%**	**73.505**	**122.270**	**48.765**
Total		**0,1819**				**680.566**	**260.149**	**-420.417**

[1]AUA for Grassland, Corn, Barley, Soybean and Field bean in Tuscany (ISTAT, 2010)
[2]AUA for Soft Wheat in Tuscany (ISTAT, 2010)
[3]AUA for Durum Wheat in Tuscany (ISTAT, 2010)
Source: own elaboration

For cereals, OA needs 13% more land than CA (13% more land for bread LFF and the 14% more land for pasta LFF). In OA (Table 2), bread and pasta account for 9% of the total LFF per capita and provide the 19% of the daily protein intake. The CA LFF for cereals consumption accounts for the 12% of the total LFF per capita. OA LFF for animal products needs 36% more land than CA. The values range between the 25% more land for organic pork to 49% for organic poultry. The OA LFF for animal protein accounts for 92% of the total LFF per capita. Beef LFF is the 28% of the total LFF, pork consumption is the 23%, while poultry represents the 13% of the total land food footprint. CA animal LFF accounts for the 89% of the total assessed per capita LFF. Beef consumption provide the 10% of protein daily intake and it has the highest LFF, with the 29% of the LFF per capita. This implies that, in CA, poultry and milk are more efficient than bovine and pork in the provision of animal protein per hectare.

Table 2. Land Food Footprint for organic agriculture

	Organic Agriculture								
	Per capita consumption (Kg)	LFF per capita (ha/per capita)	Relative Impact of products	Protein supply quantity related to daily protein intake	Calorie supply quantity related to daily calorie intake	Total LFF (ha)	Total AUA in Tuscany for category	Gap between land use and LFF	% Difference in LFF compared to Conventional
Beef	19,3	0,0778	28%	10%	3%	291.083			32%
Pork	37,3	0,0634	23%	15%	8%	237.308			25%
Poultry	18,9	0,0346	13%	8%	2%	129.440			49%
Total Meat	75,5	0,1758	64%	33%	13%	657.831			33%
Milk and diary	260	0,0780	28%	21%	10%	291.910			43%
Total Meat and Milk	**335,5**	**0,2538**	**92%**	**54%**	**23%**	**949.741**	**137.879**	**-811.862**	**36%**
Bread (Soft wheat)	32,85	0,0094	3%	9%	7%	35.125	19.419	-15.707	13%
Pasta (Durum wheat)	24	0,0133	5%	8%	7%	49.899	102.851	52.952	14%
Total Bread and Pasta	**56,85**	**0,0227**	**8%**	**16%**	**13%**	**85.025**	**122.270**	**37.245**	**14%**
Total		**0,2765**				**1.034.765**	**260.149**	**-774.616**	**34%**

Source: own elaboration

With reference to the gaps between LFF and available land, Tables 1 and 2 describe a similar situation for CA and OA. Considering CA the worst land unbalance is due to the grassland for animal food whose LFF value is more than four times greater than the temporary grass area (concentrate feed) and than pasture available at regional level (137.879). It must be noted that, differently from meat and milk, the sum of cereals agricultural land in Tuscany exceeds for 48.765 hectares the CA pasta and bread LFF. This underlines that changes in agricultural management could potentially address the gap between CA bread LFF and available agricultural land by increasing soft wheat cultivated area. For CA, the land displacement at regional level is relative to animal food LFF; for cereals there is export of virtual land for durum wheat and import of virtual land for soft wheat. Considering OA, there is scarcity of available land for meat, milk and bread. In particular, we have land unbalance for 811.862 hectares for feed and pasture. For pasta the locally available agricultural land is enough, while for bread the land footprint is 15.707 ha greater the available land. For OA bread and pasta LFF and available land balance is affordable at regional level by shifting agricultural area from durum to soft wheat.

Table 3. Land Food Footprint for meat and milk, by crop type

	Meat and Milk per capita LFF (ha)		% of Incidence of Meat and Milk LFF on land use	
	Conventional	Organic	Conventional	Organic
Temporary grass	0,0969	0,1558	60%	61%
Maize	0,0124	0,0133	8%	5%
Barley	0,0310	0,0418	19%	16%
Soybean/field bean	0,0220	0,0429	14%	17%
Total	**0,1622**	**0,2538**	**100%**	**100%**

Source: own elaboration

Considering in detail the meat and milk LFF composition the temporary grass (concentrate feed), both in CA and OA, represents more than 60% of the total (Table 3). Concentrated livestock feed is locally obtained by Maize, Barley, Soybean and Field bean.

The second scenario "diet change", with reduced consumption of animal protein, shows a greater LFF reduction for the OA than for CA (Table 4) with respect to the status quo scenario. In fact, the greater land requirements for livestock products produce a greater impact on organic consumption, shrinking the gap between the two farming systems (Fig. 5). Results of the "diet change" scenario show that with a 50% reduction of animal proteins, OA has a LFF that is very close to the CA LFF under the "status quo" scenario; this finding suggests that diet shift toward vegetable protein enhances OA capabilities to ensure food security. Nevertheless, the gap between OA and CA LFF under this scenario is still around 30%.

Table 4. Land Food Footprint for bread, pasta, meat and milk

		Land Food Footprint per capita (ha/per capita)	LFF net change compared to the status quo	Total Land Food Footprint (ha)	Total AUA in Tuscany	Total Land difference	% Decrease
Status quo	Organic	0,2765	-	1.034.765	754.345	-280.420	
	Conventional	0,1819	-	680.566		73.779	
Diet change	Organic	0,1827	-0,0938	683.845		70.500	34%
	Conventional	0,1283	-0,0535	480.328		274.017	29%
Closed Loop Farming	Organic	0,1164	-0,1601	435.536		318.809	58%
	Conventional	0,0916	-0,0902	342.844		411.501	50%
Vegan diet	Organic	0,0890	-0,1875	332.925		421.420	68%
	Conventional	0,0748	-0,1070	280.090		474.255	59%

Source: own elaboration

With reference to the "closed loop farming" scenario, we have an increased reduction in the gap between OA and CA LFF from 34% to 21%. As shown in Table 5, available land in rotation per capita is greater for OA than for CA, due to different rotation patterns for the production methods. Consequently, a greater amount of meat and then of protein is produced with OA (15 kg) in respect to CA (13 kg).

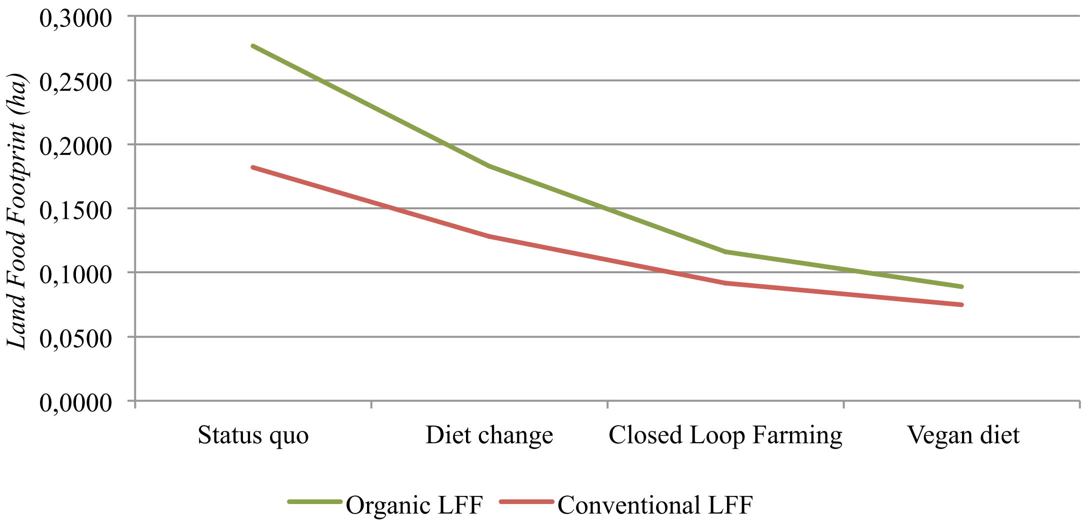
Table 5. Production possibilities using land in rotation

	Conventional	Organic
Land food footprint (only meat)	0,1180	0,1758
Land in rotation per capita	0,0196	0,0341
% of LFF covered by land in rotation	17%	19%
Kg of meat producible	13	15

Source: own elaboration

With reference to the fourth scenario, to evaluate the impact of livestock in term of sustainability of farming systems (OA LFF vs CA LFF) we also assume a diet shift towards 100% animal protein with the "vegan diet" scenario. The results show that there is a greater reduction in organic land food print (-68%) than for conventional LFF (-59%), shrinking the gap between the two farming systems with only 16% of more land for organic production (Fig.5) showing the role of diet in affecting sustainability of farming systems.

Fig. 5. OA LFF, CA LFF and the nexus of diet



Source: own elaboration

The organic farming system capability of supplying food to the population is heavily reliant on dietary composition. Sustainable farming system asks for change in consumption patterns towards more healthy, consciousness and responsible choices in term of trade-off between consumption of vegetal and animal proteins.

CONCLUSIONS

The study, whilst confirming that organic agriculture needs more land than conventional one, underlines the role of diet changes in reducing the difference between organic and conventional agriculture land food footprint. Consistently with the literature, organic agriculture needs more land (around 34%) than conventional agriculture, but in the case of vegan diet it falls to 16% indicating that organic production systems is able to satisfy food demand under specific conditions. This confirms that diet nexus is a crucial factor and that it has an important impact on the sustainability of agricultural production systems and societies. Results show the potential effect of dietary shift toward vegetable protein in terms sustainability of food production systems. Reduction in animal protein intake results in a positive impact on the land food footprint which is greater for organic. The study shows that transition towards organic agriculture asks for the integration of several strategies involving technical, consumption and policy issues. Currently organic farming shares cultivars with conventional farming. In this perspective, a central role is played by crop breeding in targeting varieties with specific characteristics for organic agriculture enhancing yields. Likewise more sustainable livestock production techniques are to be found and adopted avoiding competition with food crops and enhancing resource use efficiency. Transition towards sustainable agriculture implies rethinking the food consumption habits and dietary patterns for internalising sustainability goals into the societies encompassing all stages from the farms to the plate. In the analysis of these results it is important to bear in mind two elements. The first, which represents the main limitation of this study, is the reliability of data sources: land food footprint assessment is extremely sensitive to yield and consumption data and these values vary considerably from one source to another. Future research could help in determining more robust results. The second element that should be noted is that land food footprint measures virtual land imports and exports. Consequently their contribution in considering local food security should not be interpreted in terms of autarky but in terms of land and fossil fuel dependency. The application of these approaches suggests the need for a demand side policy integration into health, agricultural and environmental policies. The dietary shift scenarios show indeed that organic agriculture may fulfil food security if measure to reduce meat consumption and food waste are undertaken and if innovation efforts are addressed to develop organic agriculture specific techniques and to select genetic material more suitable for organic practices.

ACKNOWLEDGMENTS

The authors are grateful for support and funding from Uniser.

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