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Sustainable agriculture, food security and diet diversity. The case study of Tuscany, Italy.

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ABSTRACT

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 resources constraints. Ecological footprints are widespread instruments for the study of human impact and dependence on natural resources. Amongst 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 given region or country. Understanding the differences between alternative production methods and the gaps between available and needed land is a crucial issue in order to integrate food security and sustainability issues into the food system. The objective of this study is to analyse the Land Food Footprint of Tuscany (Italy) for both organic and conventional agriculture, taking into account the nexus of diet. In this aim, Land Food Footprint for the considered production processes is assessed under four different diet scenarios with different levels of animal protein consumption. The study suggests that the gap between land needed by organic and conventional agriculture varies considerably between vegetable and animal products. It confirms that organic agriculture needs more land than conventional one but the gap between land footprints shrinks because of dietary changes. In this study, the most important finding is that organic agriculture might feed the case study population if the diet shifts towards a reduced intake of animal protein. In fact, with a diet reduction of 50% in animal proteins, the organic land food footprint value is equal to the conventional land food footprint under the status quo diet scenario indicating that organic agriculture would be able to address food security issues if food consumption was properly adapted to agriculture carrying capacity.

1. Introduction

The world's population is growing rapidly. World's concerns about run-away population growth have raised the debate about natural resource carrying capacity for human life. The population in urban settlement has shifted from 746 million of 1950 to 4,3 billion of 2020, representing the 56% of the total population. In Italy, the 71% of population lives in urban areas (World Bank, 2020). People migration from the countryside increases food demand and it can be associated to a higher likelihood of farmers losing their lands to urbanisation, thus leading to a loss of cultivated land. It is estimated that 2050 agricultural production would need to increase by a 50% to meet food demand of a global population assessed up to 9 billion people (Alexandratos and Bruinsma, 2012). The challenge of agriculture is to feed an increasing world population with a finite and degraded agricultural land. Agriculture intensification is traditionally thought as the unique strategy to attain food security goals at global level (Bengochea Paz et al., 2020). In fact, during the last decades, the increasing food demand has been met by increasing crop yields through the implementation of high inputs, industrialised farming practices following the green revolution approach (Borlaug, 2000). As a consequence, the food system is increasingly contributing to environmental degradation and resource depletion both at local and global level (Hanson et al., 2008; Hu et al., 2017; Guyomard et al., 2011; Montoya et al., 2020). Food policies urgently need to face the problems of natural resources scarcity and sustainability of food production/consumption systems. In order to ensure

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the viability of a sustainable food system, agricultural productivity needs to be coupled with resource conservation and health protection (Bengochea Paz et al., 2020; Muller et al., 2017; Tilman et al., 2002; Walters et al., 2016) fulfilling the Sustainable Development Goals (SDGs). Agro ecological farming systems could represent a valid solution to attain agriculture sustainability but its role in ensuring world food security is still discussed (Connor, 2018; Rockström et al., 2017). The debate around the viability of agro ecological farming systems is arising, since food security targets are usually associated with high-yield, intensive agriculture (Reganold et al.; 2016; Tuomisto et al., 2012, Power, 2010). As organic and biodynamic agriculture yields are lower than those of conventional agriculture, more land is necessary for organic agriculture to produce the same amount of food as the conventional one (Seufert et al., 2012). In addition, lower productivity implies less output per amount of cultivated area and less environmental advantages if calculated per amount of food supplied rather than per agricultural area (Meier et al., 2015). Several research studies have investigated different aspects of organic agriculture, including its environmental performances (Reganold and Wachter, 2016), Neely and Fynn, 2012; Schader et al., 2012), soil nutrient and fertility aspects (Badgley et al., 2007) or agro ecological farming contribution in terms of ecological services and biodiversity issues (Cazalis et al., 2018; Mitchell, 2013) verifying their contribution to sustainability also in terms of SDGs (Eyhorn et al., 2019). Some emerging studies are providing evidence of the feasibility of agro ecological agriculture by adopting a rounded approach to the food system which integrates farming practices, consumption and dietary patterns aspects (Garnett. et al. 2013; Hunter et al., 2017; Muller et al.,2017; Galli et al., 2020). In this context, the contribution of this study is to investigate organic agriculture (OA) viability in comparison to conventional agriculture (CA), taking into account different aspects of the production and consumption processes. The following main aspects of the food systems are considered: farming practices (organic/biodynamic or conventional agriculture), farm typologies (mixed vs. specialised farms) and dietary diversity, in order to assess whether and under which conditions organic agriculture shows feasibility in terms of land needed to address food security issues. For this purpose, the Land Footprint approach is applied in order to assess the land needed to meet the local population demand of food under different combinations of diet, farm typology and farming practices. The Land Footprint refers to “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 (LFF) is the quantification of the per capita Utilised Agricultural Area (UAA) needed to feed the local population and it is essential in order to integrate food security into sustainable agriculture objectives. According to the World Bank (2014) the value of Arable Land per Person in Europe is equal to 0.2 hectare, whereas in Italy equals 0.1 hectare per person. Hence, the agricultural land scarcity is an emerging problem that food policy needs to address in attaining sustainability. The purpose of this study is to assess the amount of land that OA and CA need to satisfy the food demand of the population of Tuscany Region, Italy, taking into account the nexus of diet. The research questions are (i) what would be the impact of a transition of the farming systems toward OA in terms of agricultural land availability and (ii) could shifts in the dietary habits and/or farm typologies reduce the gap between OA and CA in terms of land food footprint? Land food footprints for organic and conventional agriculture are assessed on the basis of three different hypothetical diet scenarios plus the status quo diet. For all these scenarios, specific crop rotation schemes and farm typology for both organic and conventional agriculture are considered. The different production and consumption patterns can affect the gap between organic and conventional agriculture in terms of land needed

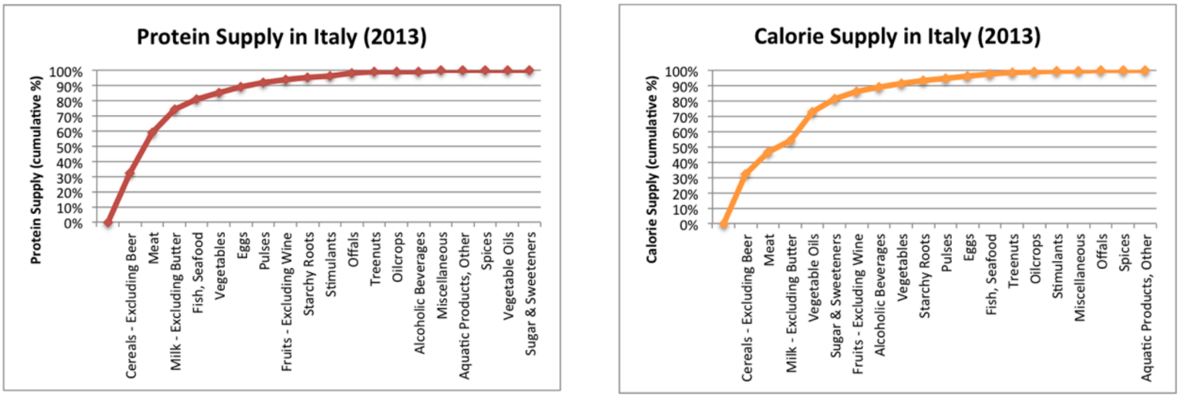
2. Materials and methods

In this paper, a land footprint approach is adopted in order to assess the food system sustainability. As expressed by O’Brien et al. (2015) it is necessary to distinguish between the Ecological Footprint and Land Footprint. Ecological Footprint theoretically measures the land area used/needed to supply resource consumption and absorb emissions. 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, has only recently been 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 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) at different scales in order to assess land use sustainability and inequality between regions or countries. Moreover, the conservation of local food systems is increasingly recognised 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. Alexander et al. (2015) in their study 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. Qiang et al. (2013) adopted a bottom-up method, using trade quantities for each product. Following Qiang et al. (2013) this study adopts a bottom-up approach based on a consumption-oriented methodology that considers the land needed to sustain the per capita annual food consumption of an individual of a given population. In this research, individual land food footprint of the per capita consumption of meat, milk, pasta and bread are assessed, 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). These food typologies are selected because they embody the major food groups 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) (Fig. 1) of the Italian diet. In addition, livestock and wheat constitute the two main agricultural production systems (ISTAT, 2010).

Data on regional yield of organic and conventional crops are used, then a food and Feed Conversion Ratio (FCR) is applied in order to assess the amount of agricultural land needed to supply one kilogram of each consumed food type. Different types of land use are considered: croplands used to produce crops for human food and grassland/croplands used to produced one kilogram of animal product (meat and milk). The conversion rate of raw materials into edible products through the primary (e.g. milling) and secondary processing (e.g. baking) is also accounted for. An example of the land food footprint approach adopted in this study is presented in Fig. 2.

With reference to animal products, this study considers different animals (ruminants and non-ruminants) and a specific conversion rate for each production level according to the approach suggested by de Ruiter et al. (2017). While de Ruiter et al. (2017) use the same feed composition amongst different livestock system, this study differentiates diet composition in function of species, genotype, and type of production (milk or meat). Yields of crops used for animal feed, expressed in tons of dry matter (DM) per hectare, are reported in Table 1 (ISTAT, 2010; (RICA Rete di Informazione Contabile Agricola 2014) both in OA and CA systems.

For animal products the specific rearing practices of Tuscany farms and their traditional rearing systems are considered, simulating two



Source: FAOSTAT, 2014b   Source: FAOSTAT, 2014c

Fig. 1. Protein and calories supply in Italy.

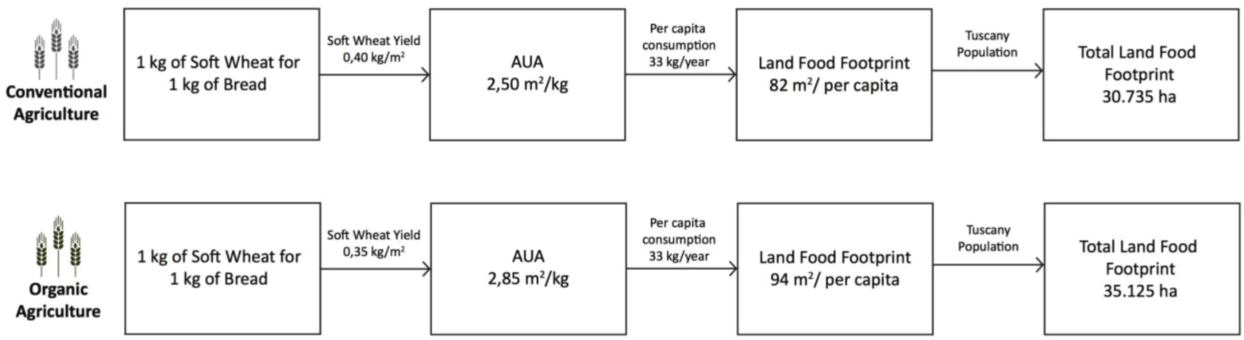


Fig. 2. Example of land food footprint assessment (organic and conventional soft wheat).

Table 1
Yield of conventional and organic crops (ton/ha DM) used in diets of animals.

Productivity (ton/ha)	Organic	Conventional
Hordeum vulgare	3,0	3,8
Zea mays	6,0	8,0
Glycine max	3,0	3,6
Vicia faba	2,8	3,0
Mixed meadows hay	4,0	5,6
Medicago sativa hay	6,0	8,1
Natural pasture grass	1,5	–

different patterns for organic and conventional rearing practices. For the organic rearing system the requirements of Reg. CE 834/2007 and subsequent changes are taken into account. In the conventional animal rearing system, indoor rearing is considered, whereas for the organic system this study assumes outdoor rearing (at least for a part of the animals' life) and more specifically, "en plein air" rearing systems are adopted for pigs.

For each animal species, a specific feeding system based on cereals and forage is hypothesised. For cattle, the grassland required for their diet is taken into account both directly (pasture) and indirectly (hay), whereas the diets of monogastric animals (e.g. chickens and pigs) mainly consist of cereals.

The nutrient requirements, the nutritional value and the ingredients of the diet are computed according to the National Institute of Agricultural Research (INRA Institut National de la Recherche Agronomique 1988) based on milk and meat forage unit for cattle and poultry, whereas for pig nutritional values of the National Research Council (NRC, National Research Council 2012) are applied.

Regional demand of meat is assumed to be supplied by dairy husbandry for the 50% and by cattle husbandry for the rest, in accordance with data provided by the National Agricultural Census in the regional livestock statistics section (ISTAT, 2010). For the meat supplied by meat cattle autochthonous and French breeds are taken into account, as well as the feed requirements for young bulls and cows, including the heifers. For meat obtained by dairy husbandry, the feed requirements and the feed ingested by young bulls were considered, while the feed assigned to cows was accounted for in milk production. In the organic system natural pasture feed is considered.

For milk production, the quantity of feed directly ingested by dairy cows, plus a quota of feed ingested by heifer is considered. In this case, differences between organic and conventional system are mainly due to the quantity of milk that is produced, the fat content of milk and the number of lactations per heifer.

For pigs, feeds for sows, weighted on number of produced piglets, are considered (NRC, National Research Council 2012). In poultry, this evaluation has not been done since the feeds ingested by poultry breeder are negligible respect to the number of chicks born per hen.

The main differences between organic and conventional systems are due to slaughter key parameters such as weight, age, yield but they are also due to the average daily gains. For cows and heifers, comparing the two systems (organic and conventional), both the length of productive life and the number of calves produced differs, as well as the number of piglets born for sows in OA and CA.

Feed conversion rate is applied to measure the amount of feed needed to produce one kilogram of animal product. Nevertheless, the amount of feed consumed by breeding animals such as the heifer is also considered in the conversion rate, because it has final impact on each kilogram of animal product supplied by the whole production cycle.

Table 2 shows differences between the FCRs of the considered farming systems, expressed in kg of dry matter (DM) for kg of animal

Table 2
Feed conversion ratios expressed as kg of feed/kg of weight gain (Giorgetti et al., 1995; (INRA Institut National de la Recherche Agronomique 1988);(NRC, National Research Council 2012) (Sirtori et al., 2010); (CRPA Centro Ricerche Produzioni Animali 2010).

Animal product	Organic agriculture		Conventional agriculture	
	FCR	% forage in feed(DM basis)	FCR	% forage in feed(DM basis)
Beef meat	16.7	71	14.8	62.5
Pig	5.4	0	4.3	0
Poultry	4.5	0	2.2	0
Milk	1.2	70	0.9	53

product. Considering all rearing phases, for ruminants, the difference in diet composition is affected by a FCR which varies in function of different fibre contents. In pig and poultry species feed differences between OA and CA are mainly due to the FCR and breeding factors.

The total amount of diet intake of animal protein is multiplied by its respective conversion ratio to obtain the total amount of crops yield needed to fulfil the diet requirements. Then the crops yield values are used to assess the land needed to supply the amount of consumed animal food and to define LFF for animal protein consumption.

The whole agricultural production cycle for each key food category including crops rotation is considered as well as all the necessary inputs to produce meat and milk, taking into account the full animal chain from cow breeding to calf. Food waste is not considered in the assessment, since it is included in the consumption values. Also, regional import and export of food have not been considered. Specifically, the agricultural area necessary to produce one kilogram of a cereal product is defined by the following Eq. (1):

$$area_i = \frac{FCR_i}{yield_i} \tag{1}$$

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

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

where $area_i$ is expressed as the sum 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 for livestock product *i*. Then, the land food footprint for the generic item *i* (LFF_i) is calculated as in:

$$LFF_i = area_i * consumption_i \tag{3}$$

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

$$LFF_{pc} = \sum_{i=1}^{k} LFF_i \tag{4}$$

As shown in Fig. 3, three different land uses are assumed: cropland for food, cropland for feed, and grassland. In the rotation pattern, two different patterns for organic and conventional agricultural practices are simulated (Table 3). Farm typologies are considered assuming specialised farms (crops farms or animal farms) and mixed farms (crops and animal farms) in which wheat is in rotation with feed. In this situation, the land utilised for feed purposes, supplying the meat or milk production systems, is accounted for in protein production (meat and milk), thus reducing the amount of LFF for wheat production, since meet and milk are obtained as side products of farm crops.

Then, as presented in section 1, the individual LFF was calculated under four diet scenarios, three of which express variation in the amount of animal protein intake, and one of these considers an animal protein intake tailored on the agricultural producing capacity in the OA And CA farming systems, characterised by differences in rotation patterns, farm practises and typologies. The four scenarios are as follow: (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) “sustainable diet”, related to “mixed farming” assuming agricultural productivity as a diet constraint; (iv) “vegan diet” with only vegetable proteins. These assumptions are in line with some studies and institutions (e.g. FAO and the Chinese Government) stressing the need to reduce meat consumption (Bryngelsson et al., 2016; FCNR, 2018; Milman and Leavenworth, 2016; Westhoek et al., 2014). The third scenario, named “sustainable diet”, constrains the diet to be compatible with a sustainable production system, as the meat that can be included in the diet is limited to the amount that can be produced using the portion of land set aside by cereals in rotation.

The amount of meat and milk consumption are converted into protein supply considering, for each food type, the protein content provided by the USDA (United States Department of Agriculture) Food Composition Databases (USDA, 2018). Then, for each of the three scenarios requiring a reduction of meat consumption, the meat protein intake is replaced by an equivalent amount of proteins provided by vegetable

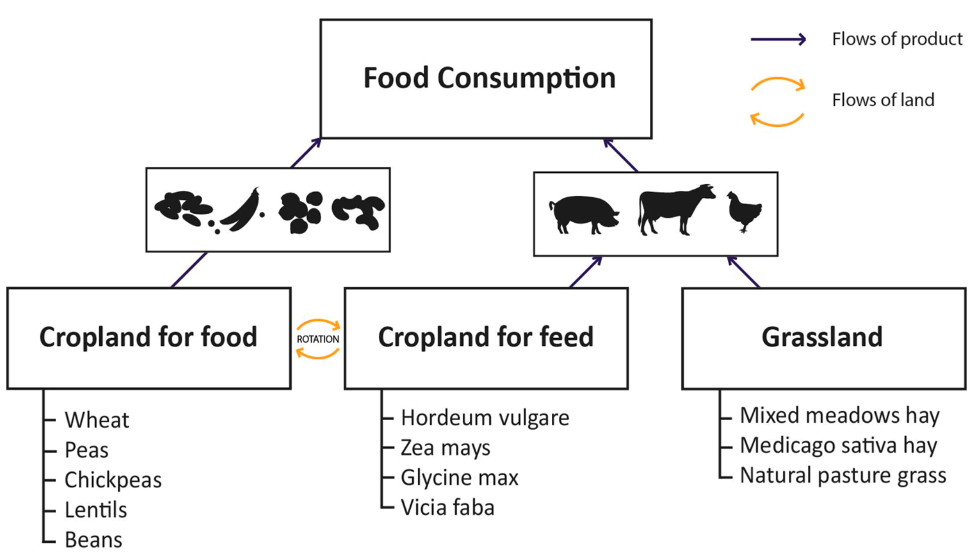


Fig. 3. Land use categories.

Table 3
Rotation patterns

Conventional						Organic					
Year	I	II	III	IV	V	Year	I	II	III	IV	V
Crop	Wheat	Feed	Wheat	Feed	Wheat	Crop	Wheat	Feed	Wheat	Feed	Wheat

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

food such as peas, chickpeas, lentils and beans. The obtained regional land food footprints for each scenario and for OA and CA are then compared to each other and with Tuscany available land (UAA), split into the different available land uses, in order to assess the regional land balance.

3. Results and discussion

The regional LFF for the "status quo scenario", shows differences in terms of land balance when compared with available regional UAA (ISTAT, 2010) and in terms of gap between OA and CA (Table 4 and 5). In the "status quo", OA needs in total 34% more land than CA (Table 5). The regional LFF for OA requires almost four times the regional UAA, while CA accounts for around the double of UAA.

The gap between OA and CA varies with respect to each food category. For cereals, OA needs 14% more land than CA (13% for bread LFF and 14% for pasta LFF). In OA (Table 5) bread and pasta account for 8% of the total LFF while the CA LFF for cereals consumption accounts for the 11% 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 represents the 23%, and poultry accounts for the 13% of the total land food footprint. CA animal LFF represents the 89% of the total assessed per capita LFF. Beef consumption has the highest LFF, with the 29% of the LFF per capita. Table 4 and 5 also show the protein and calorie conversion efficiency. In CA meat and milk, on average, provide 146 kg of proteins per hectare and 1829 Mega Calories (Mcal) per hectare. Cereals are more efficient, providing 355 kg of proteins per hectare and 9076 Mcal per hectare. In OA animal products provide 88 kg/ha of proteins and 1130 Mcal/ha, whereas wheat products provide 308 kg/ha of proteins and 7872 Mcal/ha. Both in CA and OA, bread is the most efficient product in the provision of protein and calorie per hectare. Amongst animal products milk is the most efficient and beef is the least efficient.

With reference to the gaps between LFF and available land, Tables 4 and 5 describe a similar situation for CA and OA. Considering CA the worst land unbalance is due to grassland needed for animal feed, whose LFF is more than four times greater than the available pasture (137.879) and crop area. It must be noted that, differently from meat and milk, the sum of cereals UAA area in Tuscany exceeds for 48.765 hectares the pasta and bread CA LFF; for cereals there is export of virtual land for durum wheat and import of virtual land for soft wheat. This underlines that changes in agricultural management towards the typology of mixed farms could potentially address the unbalance between bread CA LFF and available agricultural land by increasing soft wheat cultivated area. These results underline the potentiality of agro ecological systems (both organic and biodynamic agriculture) in terms of food security targets under sustainable nutrition scenarios (reduced consumption of animal protein or vegetarian diet). In fact, those agricultural systems, based on mixing animal and crop production in a circular economy perspective, show a stronger effect in term of land use efficiency, since the complexity and length of their rotation patterns allow animal protein production as secondary products of cereals production. These effects are higher if diet choices are based on agricultural carrying capacity and animal protein consumption is sized on the amount of animal protein produced by cereal rotation. For CA, the land displacement at regional level is relative to animal food LFF. A similar situation is depicted for

Table 4
Land food footprint for conventional agriculture

Conventional agriculture	Per capita consumption (kg/year)	LFF (ha/per capita)	Relative impact	Protein efficiency (kg/ha)	Calorie efficiency (Mcal/ha)	Total LFF (ha)	Total UAA in Tuscany for category	Gap between UAA and LFF
Beef	19,3	0,0527	29%	71	725	197.185		
Pork	37,3	0,0477	26%	132	2055	178.679		
Poultry	18,9	0,0176	10%	188	1538	65.781		
Total Meat	75,5	0,1180	65%	130	1439	441.645		
Milk and diary	260	0,0442	24%	193	3000	165.416		
Total meat and milk	**335,5**	**0,1622**	**89%**	**146**	**1829**	**607.061**	**137.879**[a]	**-469.182**
Bread (Soft wheat)	33	0,0082	5%	436	10,360	30.735	19.419[b]	-11.316
Pasta (Durum wheat)	24	0,0114	6%	274	7791	42.771	102.851[c]	60.080
Total bread and pasta	**56,85**	**0,0196**	**11%**	**355**	**9076**	**73.505**	**122.270**	**48.765**
Total		**0,1819**				**680.566**	**260.149**	**-420.417**

aUAA for Grassland, Corn, Barley, Soybean and Field bean in Tuscany (ISTAT, 2010).
bUAA for Soft Wheat in Tuscany (ISTAT, 2010).
cUAA for Durum Wheat in Tuscany (ISTAT, 2010).

Table 5
Land Food Footprint for organic agriculture.

Organic Agriculture	Per capita consumption (kg/year)	LFF (ha/per capita)	Relative impact	Protein efficiency (kg/ha)	Calorie efficiency (Mcal/ha)	Total LFF (ha)	Total UAA in Tuscany for category	Gap between UAA and LFF	% Difference in LFF compared to conventional
Beef	19,3	0,0778	28%	48	491	291.083			32%
Pork	37,3	0,0634	23%	99	1547	237.308			25%
Poultry	18,9	0,0346	13%	95	781	129.440			49%
Total meat	75,5	0,1758	64%	81	940	657.831			33%
Milk and diary	260	0,0780	28%	109	1700	291.910			43%
Total meat and milk	**335,5**	**0,2538**	**92%**	**88**	**1130**	**949.741**	**137.879**	**-811.862**	**36%**
Bread (Soft wheat)	32,85	0,0094	3%	381	9065	35.125	19.419	-15.707	13%
Pasta (Durum wheat)	24	0,0133	5%	235	6678	49.899	102.851	52.952	14%
Total Bread and Pasta	**56,85**	**0,0227**	**8%**	**308**	**7872**	**85.025**	**122.270**	**37.245**	**14%**
Total		**0,2765**				**1.034.765**	**260.149**	**-774.616**	**34%**

OA: there is an unbalance between available land and meat, milk and bread LFF, whereas for pasta LFF the locally available agricultural land is sufficient to satisfy the local demand. For OA, the balance between bread and pasta LFF and available land would be positive at regional level by shifting agricultural area from durum to soft wheat.

Considering in detail the meat and milk LFF composition it can be noted that the temporary grass, both in CA and OA, represents more than 60% of the total (Table 7). Concentrated livestock feed is locally obtained by maize, barley and soybean (replaced by field bean in the OA system). The percentage of incidences of crops assigned to animal feed (i.e. maize, barley and soybean/field bean) on land use are always lower than 19%. Organic farms require more land to sustain animal production due to different motivations: the lower yields of crops, the higher use of pasture, the replacement of soybean with field bean and the lower FCR used.

The second scenario "diet change", with reduced consumption of animal protein, shows a greater LFF reduction for OA than for CA (Table 8), compared 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. 4). Results of this scenario show that a 50% reduction of animal proteins would bring the OA LFF very close to the CA LFF under the status quo (respectively, the OA LFF is 0,1823 ha/per capita whereas the CA LFF equals to 0,1819 ha/per capita); this suggests that animal protein substitution by vegetable protein would allow OA to ensure food security. Nevertheless, the gap between OA and CA LFF within this scenario is still around 30%.

With reference to the "sustainable diet" scenario, based on a mixed farming system productivity, a relevant reduction in the gap between OA and CA LFF from 34% to 21% respectively,(about 40% lower than the CA LFF for the status quo scenario) is found. This result underlines that sustainable agriculture viability asks for a societal transition towards sustainable diet. As shown in Table 6, available land in rotation per capita is greater for OA than for CA, due to different rotation patterns for the two production methods. Consequently, a greater amount of meat and then of protein is produced with OA (15 kg, around 0,2 kg per week per person) compared to CA (13 kg). It is interesting to note that this amount of meet (0,2 kg per week per person) is almost the quantity traditionally assumed in the Mediterranean diet, shaped on local

Table 6
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

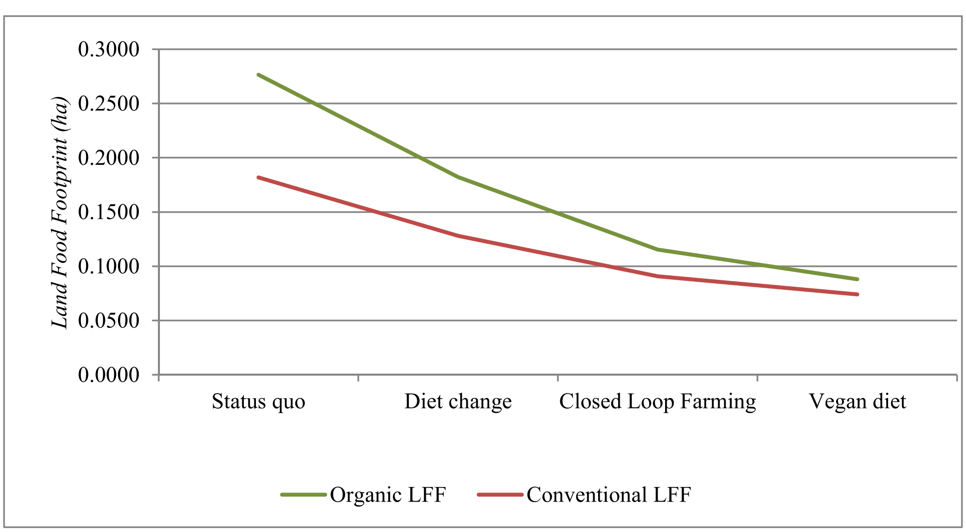


Fig. 4. OA LFF, CA LFF and the nexus of diet.

Table 7
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%**

agriculture features.

With reference to the fourth scenario ("vegan diet"), results show that there is a greater reduction in organic LFF (-68%) than in conventional LFF (-59%), shrinking the gap between the two farming systems with only 16% of more land for organic production (Fig. 4) showing the role of diet in affecting sustainability of farming systems. It must be noted that the OA LFF in this scenario is 51% lower than the CA LFF under the status quo scenario.

Results of this study suggests that organic agriculture capability of supplying food to a given population is heavily reliant on diet habits stating a strong nexus of LFF with diet. Sustainability of farming system is linked to change in consumption patterns towards healthier, more conscious and responsible choices in terms of trade-off between consumption of vegetal and animal proteins. The dietary approach to LFF provides an insight on the performance of OA in terms of food security assurance. Under specific dietary patterns the OA land footprint is lower than the current CA land footprint, implying that changes in animal protein consumption would be required for OA to represent a viable answer toward sustainable food systems, even in the perspective of a growing global population. Consistently with Muller et al. (2017) this study confirms that organic agriculture needs more land than conventional production systems, so that its viability depends on the transition towards sustainable diet choices.

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, the contribution of this approach in considering regionally based food security should not be interpreted in terms of autarky but regarded as the advantages of a shorter supply chain, which allows to reduce fossil fuel consumptions in food transports.

4. Conclusions

The main contribution of this paper is to underline the role of farm typologies and diet changes in the pursuit of sustainability and food security targets. The nexus of diets, in fact, reveals that OA, under specific dietary patterns, may require less land than CA under current dietary patterns. The study provides evidence that the gap between OA and CA can be reduced with dietary shifts up to a small gap that can be easily faced by research efforts in terms of OA dedicated to crop breeding and technological innovation. Currently OA farms use almost the same crops of CA but cannot use the same external inputs as CA. The most significant advantages of the organic rearing system are linked to the improvement of animal welfare (less stress on animals), fewer breeding problems and longer productive lives. That is even truer in relation to well-managed organic farms where high-quality forages and grazing systems are adopted.

In this perspective, a central role is played by crop and animal breeding research in selecting crop varieties and animals, allowing higher yields under OA conditions and thus pursuing sustainable productivity of agriculture. Likewise, more sustainable livestock production techniques are to be found and adopted, avoiding competition with food crops and enhancing resource use efficiency and reuse of food waste as feed in a circular economy perspective. In addition, reduction of food waste can improve OA performance in terms of LFF.

This study suggests that the transition towards organic agriculture asks for the integration of several strategies and policies in a systemic approach, considering production and consumption issues in the implementation of horizontal policies. The diet nexus approach provides insights for policy makers in terms of actions required to promote dietary changes as a key tool to promote healthy diet habits, sustainable agriculture and food security at global level. Transition towards sustainable agriculture implies rethinking the food systems as well as consumption habits and dietary patterns. This would allow to internalise sustainability goals into the demand side, involving all food chain stages from farm to fork. The application of these approaches calls for the integration of a demand side policy into health, agricultural and environmental policies implementing communication and education strategy to fasten transition towards sustainable food consumption as a necessary step for the viability of agro ecological systems. The dietary shift scenarios show indeed that organic agriculture may fulfil food security if measures 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 a sustainable intensification of organic agriculture. Further research is needed to better explore the role of traditional diets and biodiversity in ensuring food security and sustainable agriculture viability.

CRediT authorship contribution statement

G.V. Lombardi: Project administration, Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Silvia Parrini:** Investigation, Formal analysis, Data curation, Writing – review & editing. **R. Atzori:** Investigation, Methodology, Formal analysis, Data curation, Visualization, Writing – original draft, Writing – review & editing. **G. Stefani:** Writing – review & editing. **D. Romano:** Writing – review & editing. **M. Gastaldi:** Writing – review & editing. **G. Liu:**

Table 8
Land Food Footprint for bread, pasta, meat and milk.

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 UAA 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	0,1823	-0,0942	682.108		72.237	34%
	Conventional	0,1280	-0,0539	478.880		275.465	30%
Sustainable diet	Organic	0,1154	-0,1610	432.060		322.285	58%
	Conventional	0,0908	-0,0910	339.947		414.398	50%
Vegan diet	Organic	0,0880	-0,1885	329.450		424.895	68%
	Conventional	0,0741	-0,1078	277.193		477.152	59%

Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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