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Food and Nutrient Supply from Organic Agriculture in the Least Developed Countries and North America

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Abstract: Although organic agriculture (OA) is praised unequivocally for its environmental and health benefits, its potential for food security is often questioned because of its perceived lower yield. Least developed countries (LDCs), which have a high prospect of conversion to OA, are underrepresented in the literature related to the yield potential of OA, and its impact on regional food security. This paper aims to assess food and nutrient (calorie, protein, and fat) supply, thereby contributing to food security, from OA using yield ratio (YR) in LDCs and to compare this with North America (NA). Literature is the main source of data to estimate YR. Food supply data available in FAOSTAT for 1963–2013 along with the YR is used to estimate food and nutrient supply from OA in 2013. YR of crops shows a higher yield from OA in LDCs compared to NA. The food supply in LDCs between 1963 and 2013 increased at a higher rate than in NA. However, per capita nutrient supply is growing at a meager rate in LDCs; calorie and protein supply are just above the minimum threshold level and fat supply is still below the threshold level. Cereal is the single most important food item contributing to nutrient supply in LDCs, indicating a lack of dietary diversity. Thus, with relatively higher yields and crop diversity, and localized production and distribution systems, OA will have important contributions in dealing with persistent food insecurity in LDCs. However, a concerted effort is necessary to achieve yield gain and wider acceptance of OA.

Keywords: yield ratio; food production; food supply; conventional agriculture; LDCs

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1. Introduction

Food security has long been a concern for human beings. The population theory proposed by Thomas Malthus in his work entitled "An Essay on the Principle of Population" raised such a concern in 1798. He pointed out that population increases in a geometrical ratio, whereas the means of subsistence increase in an arithmetical ratio. This consequently results in famine, which he defines as the last and most dreadful mode by which nature represses a redundant population [1]. However, this influential proposition by Malthus has been argued as a myth or fallacy [2–4]. Technological advancement in agriculture, especially the green revolution, and the successful attempts to make a sharp reduction in the population growth rate, particularly in developed countries and also partially in developing countries like China have contributed to the production of sufficient food at the global level [2–4]. Similarly, increasing ease in the flow of agricultural produce across the globe either as food aid or as trade has contributed to overcome the anticipated famine.

Currently, the world produces ample food to feed its entire population. In 2013, the world food supply constituted a calorie supply of 2884 kilocalories (kcal)/capita/day, which reached 2927 kcal/capita/day in 2018 [5]. In both cases, the food supply was above the minimum threshold level of 2100 kcal/capita/day. However, despite this global achievement in producing sufficient food, 746 million people globally were severely food insecure in 2019. The recent increase in this number, from 586.0 million in 2015, as well as an anticipated rise due to the COVID-19 global pandemic, remain important international concerns exerting critical pressure in achieving Sustainable Development Goal #2 (Zero Hunger) targets 2.1 and 2.2 [6]. The vast majority of these severely food insecure people are residing in developing countries. In the case of least developed countries (LDCs), 19.2% of their population was severely food insecure in 2019 compared to 9.2% at the global level [6].

Most of these populations are smallholding farmers. They were not able to enjoy the benefits of the green revolution mainly due to their limited financial, physical, and human capital [7,8]. Moreover, the green revolution, characterized by the excessive use of external inputs, is often criticized for its negative ecological, social, and economic effects. Falling ground water tables, reduced agro-biodiversity, degradation of natural resources, and human health hazards are associated with the indiscriminate use of such external chemical inputs [8–10]. Thus, it raises a concern for its sustainability.

New technologies that build on the efficient use of local resources, readily available in rural areas of LDCs, will be crucial in increasing food and nutrient supply thereby dealing with the food insecurity in the region. Organic agriculture (OA) is one among such technologies [4,8,10–19]. However, skepticism exists concerning its yield, which is supposed to be lower compared to the external inputs based intensive agriculture (conventional agriculture—CA) [20]. Thus, there are concerns regarding OA having negative consequences on the global food supply [21]. Despite such skepticism, Badgley et al. [20] put forth evidence showing that although OA reduces the overall yield in developed regions, it will have an overall positive impact on the global food supply. The study, however, grossly divided the countries into developed and developing countries disregarding the severity of food insecurity problems in LDCs. Thus, its application to LDCs is difficult to establish. Furthermore, in the meta-analyses comparing the yield between OA and CA, observations from LDCs are heavily underrepresented [20,22–26]. This is also pointed out by Meemken and Qaim [13]. OA being a technology that relies on local resources, the assessment of its overall impact on food supply in LDCs is crucial in promoting the technology thereby tackling the overarching problem of food insecurity in the region. Therefore, this paper explores the contribution that OA could make in food and nutrient supply, which will have a direct implication for food security in LDCs, regions dominated by subsistence farmers. Thus, a focus in LDCs with ample number of cases is the novelty of this paper. Moreover, a comparison is made with the cases of developed countries, specifically North America (NA) where the share of OA retail sales is the largest in the world and OA is the fastest growing food sector, agriculture is industrialized, and obesity is a growing health concern [27]. Socio-economic prospects of organic agriculture in LDCs, where food insecurity is persistent and food sovereignty remains a critical issue, are discussed in relation with different dimensions of food security based on the literature.

2. Materials and Methods

2.1. Concepts: Organic and Conventional Agriculture

Organic agriculture is defined as a production system that "relies on ecological processes, biodiversity, and cycles adapted to local conditions, rather than the use of inputs with adverse effects" by the general convention of IFOAM in 2008 [28]. Organic agriculture aims to benefit the shared environment and promote fair relationships and good quality of life for all involved. Avoiding the use of synthetic/chemical fertilizers and pesticides is the best-known practice of organic agriculture. Hence, the organic agriculture (OA) considered for this paper include the practices that may also be called agro-ecological, sustainable, or ecological agriculture [11] without the use of synthetic fertilizers and pesticides [29]. Such practices utilize locally available natural nutrient-cycling processes in order to sustain and regenerate the soil quality, and exclude the use of synthetic chemicals [11,27–29]. Examples of such practices could be cover crops, manures, compost, crop rotation, intercropping, biological pest control, and the system of rice intensification (SRI) [4,20,30]. Thus, these technologies will have environmental benefits as well as socio-economic benefits. This paper deals particularly with the socio-economic benefits, i.e., food supply (availability) in LDCs, and also with food sovereignty [11,29].

Conventional agriculture (CA), which is also called modern agriculture or industrial agriculture is generally regarded as capital-intensive large-scale agriculture often with monoculture of crops and intensive use of external inputs—specifically chemical inputs—such as fertilizers, herbicides, and pesticides [31–33]. It also includes intensive animal husbandry. CA is admired for its contribution to the recent increase in food production and supply [33], but at the same time concerns for its sustainability have been raised by several studies due to its adverse impact on the environment, society, and economies [8,10,34].

2.2. Data Source

Data on the production and supply of different food categories and the nutrient supply from 1963 to 2013 on a regional basis were compiled from the FAOSTAT [5]. FAOSTAT has adopted a new approach in estimating food balances from 2014, which limits a possibility of extending the study period beyond 2013. Similar data available in FAOSTAT are used by other studies as well to estimate the food production through alternative farming practices such as organic agriculture and family farms [20,35]. Data on nutrient supply comprises calories, protein, and fat, low levels of which are important indicators of food insecurity. The categorization of food crops is based on the Food and Agriculture Organization of the United Nations (FAO) categorization. Similarly, categorization of the region into least developed countries is based on the FAO categorization. Under such categorization, the vast majority of the countries defined as LDCs are from Eastern, Western, and Middle Africa and a few from South and South-East Asia. North America (NA) is considered as a case of a developed country for comparison in this study. NA is one of the most advanced regions in agricultural production practice and a pioneer in agriculture technology development. It is also the region with the world's largest share of OA retail sales and where OA is also the fastest growing food sector [27]. Within NA, only the data from the USA and Canada are incorporated as they represent vast agricultural areas, both conventional as well as organic.

The socio-economic prospects of OA and challenges to upscale OA is drawn from a review of the relevant literature.

2.3. Data Analysis

Yield ratios (YR), which is a ratio of yield from OA to CA, were compiled through the literature that focuses on comparative yield between CA and OA. The literature consists of data based on research plots, farm surveys, as well as farmers' fields mainly from paired studies. Some of them are based on yields before and after conversion to organic methods on the same farm. Most of these cases use data from plant foods and a few from animal foods. YR data are not available for sugar and sweeteners, vegetable oils, meat and offal, animal fats, and eggs. Following Badgley et al. [20], an average of all plant foods, and all plant and animal foods were used for the food categories where the yield data to estimate yield ratio could not be traced in the literature.

A total of 906 cases were compiled from various sources (Supplementary Material). This includes 258 cases from LDCs and 648 from NA (Table 1). Around 87% of NA cases are from peer-reviewed journal papers, while the remaining 13% of cases are from research reports published in various forms such as research reports, academic theses, and field data. In the case of LDCs, around 62% of the data are from refereed journals and the remaining 38% from research reports.

We tried to be as conservative as possible while calculating YR by treating the YR greater than four as outliers to avoid any bias for OA. Similarly, we included studies regardless of duration, despite the observation that the YR initially declines but thereafter may increase with time [24,36]. Hence, the YR we observed for LDCs i.e., 1.05 was low compared to 1.79 found by Pretty et al. [37] from 360 reliable yield comparisons from 198 projects in Africa. Badgley et al. [20] also reported a YR of 1.8 in developing countries. In the case of LDCs, there is a tendency that the yield of OA is often compared with resource-poor methods of subsistence farming in the region, which may exhibit low yields because of farmers' limited access to purchased inputs and extension services. This could be an important reason for the higher YR reported by the aforementioned studies in LDCs or developing countries. Similarly, lack of scrutiny in selecting the cases for the study is an important reason for this overestimation. Following de Ponti et al. [23] and Seufert et al. [24] the cases in this study were selected carefully. For instance, out of 47 cases reported from LDCs in Badgley et al. [20] only three are included in this study after referring to the original sources.

Table 1. Yield ratios of major food categories.

Crop Categories	LDC			NA		
	Average	S.D.	Count	Average	S.D.	Count
Cereals	1.10	0.39	170	0.76	0.27	333
Starchy roots	1.10	0.12	4	0.97	0.24	14
Pulses	1.24	0.54	10	0.90	0.19	105
Oil crops	0.96	-	1	0.62	0.27	17
Vegetables	0.89	0.13	63	1.01	0.56	117
Fruits (excluding wine)	1.12	0.46	10	0.94	0.35	54
Milk (excluding butter)	-	-	-	0.86	0.10	8
All plant foods	1.05	0.36	258	0.84	0.35	640
All plant and animal foods	1.05	0.36	258	0.84	0.35	648

Sources: Please refer to Supplementary Material.

The YR observed for NA is 0.84. This observation is lower than the 0.92 reported by Badgley et al. [20], 0.91 reported by Stanhill [22] for developed countries, and 0.90 for North America [26]. However, this is relatively higher than 0.80, as reported by de Ponti et al. [23] and Kniss et al. [38] and 0.75 as reported by Seufert et al. [24]. It is agreed that the YR is highly contextual and shows the possibilities of OA attaining or even exceeding the yield of CA.

Organic food production (Equation (1)) and food supply (Equation (2)) are estimated based on the production and supply data of the major food categories and YR as follows:

$$Estimated\ Organic\ Food\ Production\ (EOFP) = Actual\ Food\ Production \times YR \quad (1)$$

$$Estimated\ Organic\ Food\ Supply\ (EOFS) = EOFP \times \frac{\text{Actual food supply}}{\text{Actual food production}} \quad (2)$$

Once the estimated organic food supply data is obtained, the estimated per capita calorie, protein, and fat supply are then calculated (Equation (3)).

$$EPES = \frac{Actual\ food\ supply}{Estimated\ organic\ food\ supply} \times Actual\ per\ capita\ energy\ supply \quad (3)$$

where, EPES is estimated per capita energy supply (estimated independently for calories, protein, and fat).

This analysis is based on the pattern of food production and the amount of land devoted to crops and pasture in 2013 [20]. As stated above, the year 2013 is the latest year FAOSTAT adopted the old food balance estimation approach. Since 2014, FAOSTAT has adopted the new food balance estimation approach, which is not consistent with the old approach. Hence, to ensure consistency, the estimations are done for 2013. Additional assumptions include: (a) the same proportion of food grown for animal feed; (b) the same proportion of food wasted; (c) the same nutritional value of food [20]. Changes in some of these practices certainly would benefit human and environmental health through reduced risk of hazardous chemical exposure. Similarly, considering the fact that OA should be built upon the locally available resources that are easily available and accessible to the small holders in LDCs, it can be assumed that any positive contribution to the agriculture production by OA could also contribute to the availability and accessibility of safe food in LDCs with better stability least affected by external shocks like COVID-19.

3. Results

This section starts by reporting a trend of food production and supply (Section 3.1) and nutrient supply in LDCs and NA (Section 3.2). The share of nutrient supply by different crop categories in the latest year of the trend period, i.e., 2013 is reported in Section 3.3. Food production and supply is related with the food availability dimension of food security, whereas nutrients supplied from diversified sources contribute to the stability dimension, and hence can be associated with better food security. Sections 3.4 and 3.5 present estimates of food and nutrients supply from OA. Any increase in food and nutrient supply, hence, can be related to better food security. These simple quantitative assessments are then supported by presenting evidence of OA's contribution to the socio-economy, and thereby, different aspects (accessibility, stability, and utilization) of food security in LDCs in Section 3.6 based on a literature review. However, upscaling OA is not an easy task. Hence, Section 3.7 reports the main challenges in upscaling OA.

3.1. Food Production and Supply Situation in LDCs and NA between 1963 and 2013

Production of food crops (cereals excluding beer and starchy roots) in LDCs is significantly low compared to NA. As can be seen in Figure 1, the difference is ever increasing in the recent decades despite LDCs achieving a relatively higher production growth rate (3.09%) compared to NA (1.76%). Domestic supply of food in LDCs throughout the period is greater than domestic production, which is reversed in the case of NA. This shows a persistent dependency of LDCs on imports. A large proportion of the food crops produced in NA (48.5%) are used for animal feed and relatively less (13.2%) for food supply. In contrast, the production and domestic supply are quite close in LDCs indicating much less is utilized as feed for livestock production (only around 8%). This indicates that NA is producing food crops not only for the food supply in the country, but also for export and input for livestock production. However, growth in feed use during the study period is high (5.31% per year) in LDCs, specifically at the later decades (8.68% after 1993). Similarly, the domestic supply and food supply is increasing at a higher rate in LDCs (2.8 and 3.3%, respectively) compared to NA (1.4 and 1.8%, respectively). This is mainly due to the increased production as well as the imports.

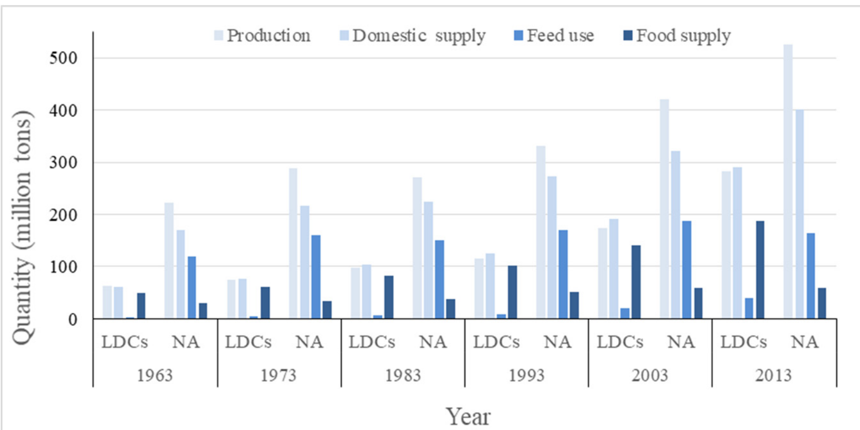
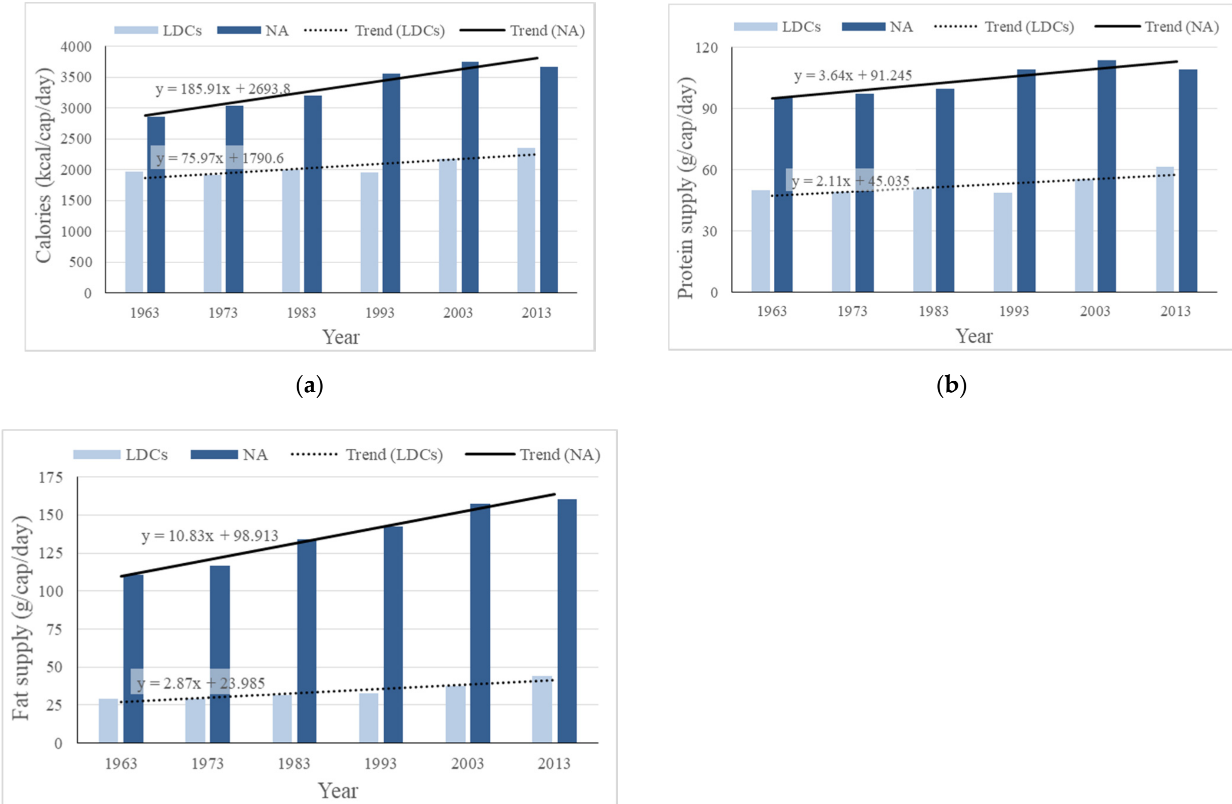


Figure 1. Historical production and supply situation of food crops through CA in LDCs and NA [5].

3.2. Nutrients Supply Situation in LDCs and NA between 1963 and 2013

Nutrients (calories, protein, and fat) supply is consistently higher in NA than that of LDCs. Moreover, nutrient supply is higher than the minimum threshold level throughout the period in NA (Figure 2). To be specific, the calorie, protein, and fat supply is greater than the minimum threshold level of 2100 kcal/capita/day, 50 gm/capita/day, and 70 gm/capita/day, respectively [39]. This could be the contributing factor to the overarching problem of malnutrition i.e., obesity in NA.



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

Figure 2. Per capita nutrient supply through CA in LDCs and NA over the study periods. (**a**) Per capita calorie supply in LDCs and NA between 1963 and 2013; (**b**) per capita protein supply in LDCs and NA between 1963 and 2013; (**c**) per capita fat supply in LDCs and NA between 1963 and 2013 [5].

In contrast, Figure 2a,b shows that the average calorie and protein supply in LDCs have just reached the minimum threshold level in 2013. Consideration of food wastage in the region might result in the short supply of these nutrients. Supply of fat is still far behind the minimum threshold level in LDCs. The comparatively higher growth rate of food supply was not translated into a higher growth rate of nutrient supply. The growth rate is merely 0.37, 0.42, and 0.92% for calories, protein, and fat, respectively against the 2.64% growth rate of food supply. The high population growth rate in LDCs during these periods is responsible for the low growth rate of nutrient supply, despite the higher growth rate in food supply. Hence, food insecurity is widespread in LDCs. The calorie, protein, and fat supply (Figure 2c) are growing positively in LDCs, though the rate is less compared to NA. The nutrient supply in the recent decade, 2013, is above the trend line (Figure 2). This shows signs of improvement in nutrient supply in LDCs.

3.3. Share of Nutrient Supply by Different Crop Categories

The food categorization by FAO [5] is adopted in this analysis. The food items listed as serial number 1 to 12 in Table 2 are important in nutrient supply. These items, in total, supply around 97 and 93% of calories in LDCs and NA, respectively; and around 92 and 96% of protein and fat, respectively, in both LDCs and NA. Hence, considering the negligible share of the food items from serial number 13 to 20, as well as the unavailability of YR data, only the initial 12 food items are considered for the analysis.

Table 2. Share of nutrient supply through CA by different crop categories, 2013.

S. No.	Food Category (Based on FAO)	Calorie Supply (kcal/capita/day)		Protein Supply (gm/capita/day)		Fat Supply (gm/capita/day)	
		LDCs	NA	LDCs	NA	LDCs	NA
1	Cereals	1346 (57.3)	812 (22.2)	31.8 (51.8)	24.0 (22.0)	6.6 (15.1)	3.6 (2.2)
2	Starchy roots	224 (9.5)	95 (2.6)	2.8 (4.6)	2.5 (2.3)	0.3 (0.8)	0.2 (0.1)
3	Sugar and sweeteners	113 (4.8)	583 (15.9)	0.04 (0.07)	0.2 (0.1)	0.01 (0.0)	-
4	Pulses	114 (4.9)	47 (1.3)	7.3 (11.9)	3.2 (2.9)	0.7 (1.5)	0.2 (0.1)
5	Oil crops	53 (2.3)	67 (1.8)	2.3 (3.8)	2.9 (2.7)	4.3 (9.8)	5.8 (3.6)
6	Vegetable oils	159 (6.8)	677 (18.5)	-	0.2 (0.2)	18.0 (41.0)	76.4 (47.7)
7	Vegetables	31 (1.3)	70 (1.9)	1.6 (2.5)	3.2 (2.9)	0.2 (0.5)	0.7 (0.4)
8	Fruits (excluding wine)	71 (3.0)	120 (3.3)	0.8 (1.4)	1.4 (1.2)	0.4 (1.0)	1.2 (0.7)
9	Meat and Offal	79 (3.4)	418 (11.4)	5.9 (9.6)	37.7 (34.6)	5.9 (13.5)	28.5 (17.8)
10	Animal fats	15 (0.6)	114 (3.1)	0.03 (0.05)	0.2 (0.2)	1.7 (3.8)	12.7 (7.9)
11	Eggs	6 (0.3)	55 (1.5)	0.5 (0.8)	4.2 (3.9)	0.4 (1.0)	3.9 (2.4)
12	Milk (excluding butter)	66 (2.8)	351 (9.6)	3.6 (5.9)	21.0 (19.3)	3.7 (8.3)	21.1 (13.2)
13	Fish, seafood	23 (1.0)	35 (1.0)	3.6 (5.8)	5.1 (4.7)	0.8 (1.8)	1.4 (0.8)
14	Sugar crops	3 (0.1)	-	0.02 (0.0)	-	0.01 (0.0)	-
15	Tree nuts	5 (0.2)	35 (1.0)	0.1 (0.2)	1.1 (1.0)	0.3 (0.7)	3.1 (1.9)
16	Stimulants	2 (0.1)	21 (0.6)	0.2 (0.3)	1.4 (1.3)	0.07 (0.2)	1.2 (0.8)
17	Spices	11 (0.5)	8 (0.2)	0.4 (0.6)	0.3 (0.3)	0.4 (0.9)	0.3 (0.2)
18	Alcoholic beverages	25 (1.1)	154 (4.2)	0.3 (0.4)	0.7 (0.6)	0 (0.0)	-
19	Miscellaneous	2 (0.1)	2 (0.1)	0.1 (0.2)	0.1 (0.1)	0.02 (0.0)	0.02 (0.0)
	Total	2348 (100)	3664 (100)	61.3 (100)	109.1 (100)	43.9 (100)	160.1 (100)

Note: Figures in parentheses indicate percentages [5].

Cereals are the single largest source of calories and protein in LDCs. However, in the case of NA, cereals along with vegetable oils, sugar and sweeteners, meat and offal, and milk have an important share in total calorie supply. Similarly, meat and offal, cereals and milk are the important sources of protein in NA. In LDCs, the next important sources of calories are starchy roots and vegetable oils with the share of 9.5 and 6.8%, respectively, in the total calorie supply. In the case of protein, pulses, meat and offal, and milk are other sources besides cereals (51.8%) contributing 11.9, 9.6, and 5.9%, respectively, to the total protein supply in LDCs (Table 2). However, vegetable oils are the largest source of fat supply in both LDCs and NA. Other important sources of fat in NA are meat and offal (17.8%) and milk (13.4%), whereas in LDCs cereals, meat and offal, oil crops, and milk contribute 15.1, 13.5, 9.8, and 8.3%, respectively, to the total fat supply. This shows that dependence on cereals in LDCs is quite high for all nutrient categories. However, in the case of NA, sources are diversified. Several food items such as sugar and sweeteners, vegetable oils, meat and offal, and milk are playing important roles in the nutrient supply. This indicates a relatively higher diversity in sources of nutrients in NA.

3.4. Food Supply Estimates from Organic Agriculture

Organic agriculture, as an improved agriculture production technology, shared only 0.67% of the total agricultural land worldwide in 2005, which increased to 0.98% in 2013, and 1.5% in 2019 [27,40,41]. Hence, considering its negligible share in the world's total agricultural land, the food supply in 2013 in both NA and LDCs is assumed to be supplied entirely by CA.

The amount of food that can be produced organically (Tables 3 and 4, column E) is estimated by multiplying the amount of food produced in 2013 (Tables 3 and 4, column A) by the average YR for respective food category (Tables 3 and 4, column D). This amount of food is then proportionally adjusted for the food supply ratio (e.g., Tables 3 and 4, column C) in order to estimate organic food supply in LDCs and NA (e.g., Tables 3 and 4, column F).

Table 3. Food supply estimates from organic agriculture in LDCs, 2013.

S. No.	Crop Categories	Pdn. in '000' MT (A)	FS in '000' MT (B)	Supply Ratio (C)	Ave. YR (D)	Est. OF Pdn. in '000' MT (E = A × D)	Est. OF Supply in '000' MT (F = E × C)
1	Cereals	163,228	118,315	0.72	1.10	179,551	130,147
2	Starchy roots	118,735	68,739	0.58	1.10	130,609	75,613
3	Sugar and sweeteners	6468	9274	1.43	1.05	6791	9738
4	Pulses	16,187	9653	0.60	1.24	20,072	11,970
5	Oil crops	18,503	3943	0.21	1.05	19,428	4140
6	Vegetable oils	3270	5196	1.59	1.05	3434	5456
7	Vegetables	34,068	32,805	0.96	0.89	30,321	29,196
8	Fruits (excluding wine)	40,374	35,888	0.89	1.12	45,219	40,195
9	Meat and offal	11,317	12,393	1.10	1.05	11,883	13,013
10	Animal fats	511	566	1.11	1.05	537	594
11	Eggs	1513	1300	0.86	1.05	1589	1365
12	Milk (excluding butter)	28,374	29,492	1.04	1.05	29,793	30,967

Note: Pdn.—production, FS—food supply, Ave. YR—average yield ratio, Est. OF Pdn.—estimated organic food production, Est. OF Supply—estimated organic food supply, MT—metric ton.

Table 4. Food supply estimates from organic agriculture in NA, 2013.

S. No.	Crop Categories	Pdn. in '000' MT (A)	FS in '000' MT (B)	Supply Ratio (C)	Ave. YR (D)	Est. OF Pdn. in '000' MT (E = A × D)	Est. OF Supply in '000' MT (F = E × C)
1	Cereals	500,091	38,013	0.08	0.76	380,069	28,890
2	Starchy roots	25,463	20,553	0.81	0.97	24,699	19,936
3	Sugar and sweeteners	21,527	22,106	1.03	0.84	18,083	18,569
4	Pulses	8750	1780	0.20	0.9	7875	1602
5	Oil crops	123,067	2000	0.02	0.62	76,302	1240
6	Vegetable oils	15,121	10,546	0.70	0.84	12,702	8859
7	Vegetables	37,284	40,299	1.08	1.01	37,657	40,702
8	Fruits (excluding wine)	29,659	38,241	1.29	0.94	27,879	35,947
9	Meat and offal	48,748	40,220	0.83	0.84	40,948	33,785
10	Animal fats	8704	2331	0.27	0.84	7311	1958
11	Eggs	6250	5124	0.82	0.84	5250	4304
12	Milk (excluding butter)	99,672	88,125	0.88	0.86	85,718	75,788

Note: Pdn.—production, FS—food supply, Ave. YR—average yield ratio, Est. OF Pdn.—estimated organic food production, Est. OF Supply—estimated organic food supply, MT—metric ton.

The estimated organic food supply in LDCs exceeds the current food supply in all food categories except vegetables. In aggregate, there will be a 7% increase in food supply through OA in LDCs. In contrast, a slight decline in food supply can be expected in NA from OA in all cases of food categories except vegetables. In aggregate, there will be a 14.4% decline in food supply through OA in NA. It is due to the lower YR in NA.

3.5. Nutrient Supply Estimates from Organic Agriculture

The current calorie supply in LDCs and NA is 2348 and 3664 kcal/capita/day, respectively (Table 5). The calorie supply in LDCs is just above the minimum threshold level, whereas in NA the calorie supply substantially exceeds the threshold. The estimation shows the calorie supply from OA to be 3042 kcal/capita/day in NA, which is less than the current calorie supply through CA, but still above the minimum threshold level. In the case of LDCs, the estimated calorie supply from OA is 2568 kcal/capita/day, which is around 10% higher than the current supply. Improvements in calorie supply from pulses and fruits can be observed in LDCs.

Table 5. Actual and estimated calorie supply (kcal/capita/day) from different categories of food, 2013.

S. No.	Food Categories	LDCs		NA	
		Actual †	**Estimated ††**	**Actual †**	**Estimated ††**
1	Cereals	1346 (57.3)	1481(57.6)	812 (22.2)	617 (20.3)
2	Starchy roots	224 (9.5)	246 (9.6)	95 (2.6)	92 (3.0)
3	Sugar and sweeteners	113 (4.8)	119 (4.6)	583 (15.9)	490 (16.1)
4	Pulses	114 (4.9)	141 (5.5)	47 (1.3)	42 (1.4)
5	Oil crops	53 (2.3)	56 (2.2)	67 (1.8)	42 (1.4)
6	Vegetable oils	159 (6.8)	167 (6.5)	677 (18.5)	569 (18.7)
7	Vegetables	31 (1.3)	28 (1.1)	70 (1.9)	71 (2.3)
8	Fruits (excluding wine)	71 (3.0)	80 (3.1)	120 (3.3)	113 (3.7)
9	Meat and offal	79 (3.4)	83 (3.2)	418 (11.4)	351 (11.5)
10	Animal fats	15 (0.6)	16 (0.6)	114 (3.1)	96 (3.1)
11	Eggs	6 (0.3)	6 (0.2)	55 (1.5)	46 (1.5)
12	Milk (excluding butter)	66 (2.8)	69 (2.7)	351 (9.6)	302 (9.9)
	Sum	2277 (97.0)	2491 (97.0)	3409 (93.0)	2830 (93.0)
	Total calorie	2348	2568	3664	3042

Note: † Actual calorie supply in 2013 through conventional agriculture; †† estimated calorie supply in 2013 through organic agriculture.

The estimated change in protein supply is presented in Table 6. The current protein supply in LDCs is 61.3 gm/capita/day, which is above the minimum threshold level of 50 gm/capita/day. OA is estimated to supply 67.6 gm/capita/day of protein in LDCs (Table 6). Consistent with the estimation of calorie supply, protein supply through OA in NA would be lesser than that from CA, but still remain well above the minimum threshold level. Fat supply in LDCs is below the minimum threshold level of 70 gm/capita/day (Table 7). OA can contribute to achieving a fat supply of 46.5 gm/capita/day, which will still be below the minimum threshold level. In the case of NA, however, fat supply will be decreased, but still remain well above the minimum threshold level.

Table 6. Actual and estimated protein supply (gm/capita/day) from different categories of food, 2013.

S. No.	Food Categories	LDCs		NA	
		Actual *	**Estimated ****	**Actual ***	**Estimated ****
1	Cereals	31.8 (51.8)	35.0 (51.8)	24.0 (22.0)	18.2 (20.1)
2	Starchy roots	2.8 (4.6)	3.1 (4.6)	2.5 (2.3)	2.4 (2.6)
3	Sugar and sweeteners	0.04 (0.07)	0.04 (0.06)	0.2 (0.1)	0.1 (0.1)
4	Pulses	7.3 (11.9)	9.0 (13.4)	3.2 (2.9)	2.9 (3.1)
5	Oil crops	2.3 (3.8)	2.4 (3.6)	2.9 (2.7)	1.8 (2.0)
6	Vegetable oils	-	-	0.2 (0.2)	0.2 (0.2)
7	Vegetables	1.6 (2.5)	1.4 (2.1)	3.2 (2.9)	3.2 (3.5)
8	Fruits (excluding wine)	0.8 (1.4)	0.9 (1.4)	1.4 (1.2)	1.3 (1.4)
9	Meat and offal	5.9 (9.6)	6.2 (9.2)	37.7 (34.6)	31.7 (34.9)
10	Animal fats	0.03 (0.05)	0.03 (0.05)	0.2 (0.2)	0.2 (0.2)
11	Eggs	0.5 (0.8)	0.5 (0.7)	4.2 (3.9)	3.6 (3.9)
12	Milk (excluding butter)	3.6 (5.9)	3.8 (5.6)	21.0 (19.3)	18.1 (19.9)
	Sum	56.6 (92.4)	62.4 (92.4)	100.5 (92.1)	83.5 (92.1)
	Total protein	61.3	67.6	109.1	90.6

Note: * Actual protein supply in 2013 through conventional agriculture; ** Estimated protein supply in 2013 through organic agriculture.

Table 7. Actual and estimated fat supply (gm/capita/day) from different categories of food, 2013.

S. No.	Food Categories	LDCs		NA	
		Actual ‡	**Estimated ‡‡**	**Actual ‡**	**Estimated ‡‡**
1	Cereals	6.6 (15.1)	7.3 (15.7)	3.6 (2.2)	2.7 (2.0)
2	Starchy roots	0.3 (0.8)	0.4 (0.8)	0.2 (0.1)	0.2 (0.1)
3	Sugar and sweeteners	0.01 (0.02)	0.01 (0.02)	-	-
4	Pulses	0.7 (1.5)	0.8 (1.8)	0.2 (0.1)	0.2 (0.1)
5	Oil crops	4.3 (9.8)	4.5 (9.7)	5.8 (3.6)	3.6 (2.7)
6	Vegetable oils	18.0 (41.0)	18.9 (40.6)	76.4 (47.7)	64.2 (48.1)
7	Vegetables	0.2 (0.5)	0.2 (0.5)	0.7 (0.4)	0.7 (0.5)
8	Fruits (excluding wine)	0.4 (1.0)	0.5 (1.0)	1.2 (0.7)	1.1 (0.8)
9	Meat and offal	5.9 (13.5)	6.2 (13.4)	28.5 (17.8)	23.9 (17.9)
10	Animal fats	1.7 (3.8)	1.7 (3.8)	12.7 (7.9)	10.7 (8.0)
11	Eggs	0.4 (1.0)	0.5 (1.0)	3.9 (2.4)	3.3 (2.4)
12	Milk (excluding butter)	3.7 (8.3)	3.8 (8.3)	21.1 (13.2)	18.2 (13.6)
	Sum	42.3 (96.4)	44.8 (96.4)	128.6 (96.3)	128.6 (96.3)
	Total fat	43.9	46.5	160.1	133.6

Note: ‡ Actual fat supply in 2013 through conventional agriculture; ‡‡ estimated fat supply in 2013 through organic agriculture.

3.6. Socio-Economic Prospects of Organic Agriculture in LDCs

Agriculture in LDCs is low-yielding and largely subsistent with the indiscriminate use of external input. This raises the issue of land and water resource degradation and food safety. Converting such low-yielding, extensive, and subsistent systems into OA is the most efficient option benefitting poor and small farmers the most [8,13,20,25,42]. OA emphasizes the use of local and indigenous knowledge and resources. The use of local resources will have a positive multiplier effect on the local economy. This helps small farmers in LDCs with a lack of capital in reducing their dependency on expensive imported external inputs thereby reducing the vulnerability to external price shocks in such inputs as experienced in 2008 [8,12,42]. Similarly, OA contributes to better utilization of food through the avoidance of direct human exposure to chemical inputs (food safety), minimizes natural resource contamination, and ensures quality products [4,8,10,19,34,43,44].

OA promotes biodiversity and contributes to reversing the soil and water degradation caused by CA [19,44,45]. OA improves the soil organic carbon, which enhances its prospects for climate change mitigation, thereby carbon credits [20,25,46]. Besides, OA offers a good option for mitigating climate change through significant avoidance of CO_2, and potential avoidance of N_2O and CH_4 [47]. Avoidance of these important GHGs from agriculture provides a better option to bring OA into the CDM mechanism of the Kyoto Protocol 1997 [48]. Such option comes with an additional source of income for the small-scale farmers as a reward for the environmental services, thereby improving their food accessibility. Similarly, OA is labor intensive. It creates employment to landless people in rural areas, which are relatively cheap labor. Consequently, the production costs of OA will be lower, thereby improving food accessibility [14,19,42].

In addition, OA contributes to increased food production at the local level in food insecure areas of LDCs. This is deemed a better solution compared to global food production, which is consistently enough to feed the global population due to the huge surplus in developed countries. Increasing reliance of LDCs on the surplus food grains in developed countries in the recent decades put LDCs in vulnerable situations especially during the global shocks which destabilized the food supply and also increased price. There was a sharp rise in the overall number of undernourished (food insecure) people during the economic crisis in 2008 [19]. Similarly, COVID-19 has threatened food security of billions of people through disruptions on local and national food systems and economies. The existing local food systems in low- and middle-income countries rely largely on food imports and the external agricultural production inputs, thereby they can easily be disrupted making them fragile to any shocks like the COVID-19 global pandemic, drought, and flood. This, consequently, will have both short-term as well as long-term implications for food insecurity due to reduced food availability as well increased food price [49]. Inclusion of organic agriculture in a local food system could enhance the resilience of local food systems and ensure a long-term sustainability mainly through a better utilization of local inputs and local food self-sufficiency, thereby creating food sovereignty. This not only reduces the reliance on imports of inputs and food (production side of the food system) but also contributes to the environmental footprint of the food, and closer relations between producers and consumers (distribution side of the food system) [42,50,51]. Hence, the potential contribution of organic agriculture to sustainable development of LDCs is widely recognized and thereby proposed as an important means to achieve the sustainable development in LDCs [8,12,14,19,24,25,44,52].

Climate change is an important factor expected to impact food insecurity adversely especially in the resource-poor regions where adaptation capacity is very limited [19]. OA could be the best option even under stresses associated with climate change [14]. OA has shown its resilience and performs better in the condition of climatic stress such as drought [14,43,44]. OA can result in the highest profitability in dry, water-scarce, least-developed regions and under uncertain conditions like climate change [25]. The UN reports the small-scale farmers in LDCs can double the food production within 10 years in critical regions through ecological methods and calls for a fundamental shift towards agroecology as a way to boost food production and improve the situation of the poorest [12]. Yield stability of OA could be a concern [45]. The absolute stability of OA yield was the same as CA. The use of green manure and enhanced fertilization will contribute to achieve even better yield stability from OA [45].

Overall, OA can contribute to strengthening social capacity and poverty reduction as well as improving the quality and quantity of natural resources in developing countries, most importantly LDCs [12,14]. OA, thereby, improves livelihoods, the viability of rural economies thereby incomes, food self-sufficiency, and food security without destroying the natural resources [50].

Critiques related to a need to expand agriculture land for OA conversion and thereby environmental destruction [13] are nullified by the higher yield ratios reported in LDCs. Moreover, with the complementary changes in the food system, OA can contribute to producing sufficient food sustainably without expanding the arable land [16] or even decreasing the harvested area by 31% [30].

3.7. The Challenges in Upscaling Organic Agriculture

Despite such prospects of OA benefitting the small-scale resource-poor farmers in LDCs, there are challenges as well. Such challenges need to be addressed in order to achieve the goal of sustainable agriculture production in LDCs through OA. OA is a practice or technology built on the optimum use of local resources. It also requires higher knowledge to sustain an anticipated yield. This is more critical in LDCs where smallholder farmers tend to have a low level of education and a limited access to required training [13,44]. This also greatly demands more research on crop and livestock breeding for OA and their efficient management practices ensuring a sustainable use of natural resources in LDCs [14,15,53]. It is estimated that crop varieties bred for the conventional high-input agriculture constitute more than 95% of organic production. Such varieties lack important traits required under low external input or organic production practices resulting in higher yield gaps [15,53].

Meeting the soil nutrients needs upon conversion to OA is another important challenge. This demands the production of an adequately high proportion of legumes, which will supply the necessary nutrients through biological nitrogen fixation [16,20,44]. The management of crop rotation and organic matters is crucial in balancing soil nutrients and maintaining the soil fertility in the OA system [14,20] and also to cope with the biotic and abiotic stresses [30]. Certification is key in realizing the improved income from OA [17,54]. However, a large proportion of small farmers in LDCs are not able to realize this important benefit in the absence of certification [13,25,54,55]. Certification is often costly, involving several accreditation organizations and infrastructure, which keeps it out of the reach for small-scale farmers in LDCs [14,46]. Hence, certification is crucial in ensuring access of such small-scale farmers to the premium market thereby increasing their income [56]. The access of small-scale farmers to certification, and thereby the organic market, can be facilitated through the approaches such as a group certification via internet control systems or participatory guarantee systems promoted by the International Federation of Organic Agriculture Movements (IFOAM) and based on trust, social networks, and knowledge exchange [57]. Management of additional labor required for OA is also an important challenge. This challenge could be tackled by providing the incentives to improve financial competitiveness of OA, which otherwise is taxed by subsidizing CA [12].

4. Discussion

There is an ever-growing difference in food crop production between LDCs and NA. NA is producing a significantly higher quantity of the food crops over the period. LDCs have to rely on food crop imports consistently for their domestic supply, despite achieving a relatively higher growth rate in the production. The consistently higher production and supply are translated to the higher, and also increasing, nutrients supply in NA throughout the period. The supply of all three nutrients is greater than the minimum threshold levels, which could be a contributing factor to the overarching health issue of obesity in NA. Hales et al. [58] reported an adult obesity rate of 39.6% in the United States (US) for 2015–2016. A trend suggests a significant increase in the adult obesity rate in the US from 1999–2000 to 2015–2016. Obesity is associated with serious health risks such as cardiovascular diseases, diabetes, cancers, and musculoskeletal disorders. The rising body mass index leading to obesity is even argued as a pandemic. Thus, with among the highest rate in the world, obesity is regarded as the important health issue in NA, specifically the US [59]. Food waste is another important issue to be considered in NA which can contribute to curb the food demand and ease the pressure in natural resources involved in its production. It is estimated that over 800 kcal per person per day is wasted by the US consumers [60]. This can go as high as 1217 kcal when the food waste is considered at the retail and consumer levels [61].

In contrast, the calorie and protein supply has reached the minimum threshold levels just recently in LDCs. Fat supply is still far behind the minimum threshold level. Even the calorie supply might still be less than the minimum threshold level if food waste is considered. The comparatively higher growth rate of food supply is not translated into a higher growth rate of nutrients supplies mainly due to the high population growth rate in LDCs. Hence, food insecurity or hunger is widespread in LDCs. Moreover, diversity in the source of nutrients is also less in LDCs. Cereals contribute significantly to calorie and protein supply in LDCs, whereas in NA cereals, vegetable oils, sugar, and sweeteners, meat and offal, and milk are the important sources of calorie supply, and meat and offal, cereals, and milk are the important sources of protein supply. Cereal is also an important source of fat supply in LDCs after vegetable oils. In NA, meat and offal and milk are an important source of fat supply after vegetable oils. This lack of diversity in food sources is also an important aspect related to food insecurity in LDCs, which can be enhanced by the food supply through OA [42].

The estimated organic food supply in LDCs exceeds the current food supply, due to the higher YR. There will be around a seven-percentage increase in food supply through OA in LDCs. However, in NA there will be a considerable decline in food supply through OA. Many agricultural soils in developed countries, including NA have been degraded by years of tillage, synthetic fertilizers, and pesticide residues. Conversion to OA on such soils typically results in an initial decrease in yields relative to conventional methods. This will be followed by increase in yields as soil quality is restored, thus there are future prospects even in NA in the long run [20,43]. Despite the decline in the food supply from OA, nutrient supply in NA will still be well above the minimum threshold levels. In LDCs, there will be around a 10% increase in calorie supply from OA. Moreover, OA contributes to an increase, though very nominal, in calorie supply from pulses and fruits as well as dietary diversity. OA can also contribute to an increased supply of protein and fat in LDCs. Fat supply even from OA, however, will be below the minimum threshold level.

All these estimates for calories, protein and fat suggest that OA has the potential to support the population in both the regions as also claimed by Badgley et al. [20]. Similarly, Muller et al. [16] reports that OA could be a viable option to feed the world even with less land than CA if combined with reductions of food wastage, and food-competing feed from arable land and subsequent reduction in production and consumption of animal products. The prospect of OA in LDCs is clearly reflected from this estimation. OA can not only help to achieve the minimum threshold level, but also help to support a substantially larger population in LDCs. OA is growing at significantly higher rate (2.5%) in LDCs compared to NA (1.06%), during these periods. OA stands as a sustainable alternative to CA, which is responsible for devastating land degradation, pollution, and biodiversity loss in developing countries [19].

Critics have pointed that any attempt to convert world agriculture to OA would increase world food prices enormously, and those most at risk would be the poorest nations that are unable to provide sufficient produce of their own [13,21]. Meemken and Qaim [13] at the same time acknowledged the lack of sufficient understanding on the net price effects of OA in poor nations. Crowder and Reganold [54] reported the price premium of 29–32%, largely based on the evidence from developed countries. Such premium is more common in the export-oriented plantation crops like coffee, cocoa, and pineapple [13], which could affect the food price less, and rather enhance their access to food with the increased income. The breakeven premium of 5–7% will be enough to match the profits from CA even with a 10–18% lower yield from OA [54]. A price premium for organic agricultural products in the local market of LDCs is non-existent [13,25,55]. Moreover, converting low-yielding and subsistent agricultural systems, which are prevalent in LDCs, to OA is regarded as the most efficient option benefitting poor and small farmers the most [8]. Considering that more than 90% of the chronically undernourished population are smallholders, any attempt to improve yield through the conversion of CA into OA benefits these huge masses to meet food demand from their own farm [25,44]. Any surplus for market will help them to generate additional cash income. Dietary diversity brought by OA will help in nutrition intake diversity. Similarly, the growing concerns about food safety, climate change, soil health, biodiversity, environmental degradation, and shocks like COVID-19 make OA a sustainable alternative to CA to fight food insecurity in LDCs, thereby contributing to the food sovereignty in those regions [20,25,44–46,50].

There are certain challenges to be overcome by OA to realize its contribution in dealing with food insecurity. The smallholder farmers in LDCs need to be provided with the technological knowledge through training and education. Similarly, there should be more research on crop and livestock breeding and efficient management of the local resources. This will be critical in both upscaling OA and also realizing the higher yield from OA. Farm management through the production of adequately high proportion of legumes, crop rotation, and organic matter recycling is crucial in dealing with the important challenge of meeting the soil nutrient demand upon conversion to OA. Access of the large proportion of small farmers to certification needs to be eased through cost-efficient mechanisms suggested and promoted by organizations such as IFOAM. Similarly, additional labor required for OA needs to be eased through the incentives to improve financial competitiveness of OA in the production process. Thus, supporting and enhancing OA (which can directly contribute to many of the 17 Sustainable Development Goals (SDGs) and is resilient to shocks like COVID-19), fostering the demand of OA, incentivizing practices such as OA that contributes to SDGs and resilient food system, and raising legal requirements and industry norms through the coherent policies will ease the challenges leading to sustainable agriculture driven by OA in coexistence with CA [13,18,46,62,63].

5. Conclusions

Though the Malthusian theory of population is argued as a myth, famine, and hunger still remain widespread in developing countries, more specifically in LDCs, amidst the ample production of food to feed the global population. The "Green Revolution", which is attributed to the introduction of high-yielding varieties with intensive use of external inputs, is well regarded for the surplus food at a global level at present. However, access to the green revolution technology has been constrained by several socio-economic factors in LDCs, where the majority of their population depend on small-scale farming with limited resources to afford the entire technology. There is ample evidence that the injudicious use of such external inputs has resulted in adverse impact on the whole agriculture system of the region leading to crop failure on several occasions. Such production-oriented input-intensive monocrops have contributed to land degradation, soil nutrient exhaustion, surface, and ground water contamination, increased pest resistance, and loss of biodiversity, thereby irreversibly damaging the local ecosystem. All these factors are having a direct impact on food security of huge sections of the rural population in LDCs for which agriculture is the mainstay of their lives. Therefore, the search for more sustainable methods of food production over the long term is deemed necessary.

Organic agriculture could serve in this direction as it can play a crucial role to feed a large portion of the population in LDCs. At the same time, OA can help to ensure environmental sustainability through nutrient recycling, mitigation of CO_2 emissions and N losses, and enhanced soil carbon sequestration. Similarly, social problems like livelihood security and poverty can be addressed as the enhanced productivity with optimum use of local resources will improve access of small-scale farmers to food. At the same time, it will reduce dependency on expensive imported external inputs thereby reducing LDC's vulnerability to external price shocks and other shocks such as the COVID-19 global pandemic disrupting the flow of those inputs. However, questions have been raised on the low yield of OA. This paper is a pursuit to analyze the prospects of OA in achieving food security goals of LDCs, by assessing the food and nutrient supply. Yield ratios of almost all crop categories in LDCs are higher than 1, signifying a higher yield from OA compared to CA. This is mainly because the agriculture in LDCs is dominated by a conventional low-input system, which itself is not producing higher yields, rather it is responsible for environmental degradation due to injudicious use of chemical inputs. The predominant conventional low-input system in LDCs provides the opportunity for easy transition from CA to OA.

Food supply in LDCs is growing comparatively at a higher rate than in NA. However, a higher growth rate in the food supply is not translated into higher growth rate in nutrient supply in LDCs due to high population growth rate in the region. Hence, the current food supply in the region is not able to meet the minimum threshold level, specifically for fat. Cereals are the single most important food items contributing to the nutrient supply in LDCs, indicating a lack of nutrient diversity in the region. In NA, however, these nutrients are supplied from different, but equally important sources like meat and milk. Under such a context, OA can contribute to an increase in the food supply from all food categories. Consequently, LDCs can achieve the minimum threshold level through OA and help in dealing with the problem of persistent undernourishment in LDCs more efficiently. However, OA itself being a technology, a due effort is needed for its dissemination and adoption by smallholder farmers currently undertaking inefficient CA or traditional agriculture. Any such efforts will reduce the yield gap substantially. Similarly, emphasis should also be put on the development of inputs necessary for OA and their sustainable use. This study relies on the simple methodology to compare the yields of OA and CA and estimate the food and nutrient supply. It is recommended to further establish the findings of this study through a meta-analysis on the yield difference between OA and CA.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13095068/s1, Table S1: Yield of organic and conventional agriculture.

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