



Carbon Credits from Organic and Biodynamic Agriculture as a Tool for Shifting the Economic Paradigm

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Abstract

Sustainable agriculture is based on organic and biodynamic farming that promotes healthy economic and environmental impacts. The dominant image of organic/biodynamic agriculture has been that “it cannot feed the world” and that “the food produced is too expensive”. This paper argues that these paradigms should be modified, firstly based on a 6-year comparative research field test (the “DOC” trial), secondly based on data from a large-scale biodynamic farm, and thirdly based on regional data from smallholder farmers in Egypt. The 6-year comparison field test in Egypt between bioDynamic (D) Organic (O) and Conventional (C) farming has demonstrated that D&O maize and broad-bean crop initially lag behind C in yield, but that after 3 years this situation changes and after 6 years D&O produce ~5% better than C. A big difference is evident in soil carbon sequestration, with D&O sequestering cumulatively 4 times more soil carbon than C during the 6 year period. The DOC trial showed an insignificant (< 5%) better profit/ha for Biodynamic & Organic crops, assuming no sales price difference between B/O and C crops. Subsequently, we included the profit to be gained from the net carbon footprint of B/O farming operations and compared the economics of the DOC trial crops, of a large-scale biodynamic farm and of a large number of regional, Egypt-wide, small-holder farmers. Carbon sequestered in soil and in trees was monetized, as well as the avoidance of greenhouse gas emissions through composting and the use of renewable energy for irrigation. These data demonstrate that carbon credits can roughly double the average Egyptian farmer's income. Therefore, we conclude that biodynamic/organic farming delivers a high quality Agro-Ecosystem Service that can produce food at competitive prices, mitigates climate change, is more sustainable, is better for the environment and can be more profitable than conventional farming. A paradigm shift about organic farming is warranted indeed!

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Introduction

It is common knowledge that climate change is already happening, and that anthropogenic activities such as farming and burning of fossil fuels are its main drivers (IPCC 2023, AR6-SPM). Over the past years, there has been a very strong policy focus on reduction of green-house gas (GHG) emissions. Many governments and international organizations have set the target of zero emissions from fossil fuel burning by the year 2050. However, emission reductions alone will not suffice to reach the IPCC 2015 Paris agreement goal of a maximum global temperature rise of 1.5 degrees relative to 1990.

Next to 50% reduction in emissions every decade, also a doubling of active Carbon-Dioxide Removal from the atmosphere (CDR) is needed to reach “Paris” (Johan Rockström *et al.*, 2017) ^[39]. Many CDR technologies have been proposed (e.g. McNutt and Caldeira., 2015) ^[26], and big industry is driving the effort of developing economic technologies for Carbon Capture and Storage, for example underground storage in deep aquifers or in depleted oil/gas fields. Such technologies are capital and energy intensive and are difficult to upscale (Pacala *et al.*, 2019) ^[30]. In this paper we argue in favor of a nature-based solution for CDR: return a big portion of the excess atmospheric CO₂ to the ecosystem from where it has come: soil.

The global soil system is the largest pool of carbon on earth, apart from the vast volume stored in solid limestone rocks (Lal 2004) ^[22]. This pool has been degraded over time by deforestation and agriculture, releasing CO₂ to the atmosphere. To reverse this trend, it is necessary to change the agricultural management practices from conventional to organic, because there is evidence that sequestration of CO₂ in soil is facilitated by organic farming practices (e.g. Krause *et al.*, 2022) ^[18].

Soil organic carbon (SOC) is the carbon stored in soil and in this paper is expressed in tons of carbon per hectare (t C ha⁻¹). Increasing SOC levels improves soil structure, water retention, nutrient availability and overall crop productivity. SOC levels can be increased through various practices such as regenerative agriculture, reduced tillage, cover cropping, and agroforestry.

For our following discussion, it is necessary to define the three key agricultural management practices to which we will refer in this paper: Conventional Agriculture here is defined as agriculture that uses chemical fertilizers (mainly NPK) as nutrient supply, uses chemical (i.e. non-natural) crop protections against weeds and pests, and may use genetically modified crops (USDA 2022) ^[43]. In agreement with Mannion (1995) ^[25] the FAO/WHO (1999) ^[11] defines organic agriculture as “a holistic production management system which promotes and enhances the agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity”. Biodynamic agriculture is based on the concept of the farm as an autonomous and living organism and structure (Steiner 1924 ^[38]; Pfeiffer, 2006 ^[33]). Farm-land soil, managed by Organic or Biodynamic practices, can be regarded as a provider of an Ecosystem Service with respect to its CO₂ storage potential. In the following we will often use the term “organic” to cover both organic and biodynamic farming, in case this is deemed to be suitable. Proposing a massive scale mutation from Conventional to Organic/Biodynamic farming as a CDR method with global impact, faces two major paradigms that portray a negative image of such practices: 1) Organic agriculture cannot feed the world, and 2) it delivers food at higher prices than conventional agriculture. These two paradigms, if true, strongly hamper the growth of organic agricultural practices. This paper will not only discuss both the true/not true nature of these two statements but will also offer solutions to create a 100% organic food production in the world. There are numerous studies comparing the yields and environmental impact of conventional and organic farming (e.g. Seufert *et al.*, 2012 ^[40], de Ponti *et al.*, 2012 ^[7], Clark and Tilman 2017 ^[5]). These meta-studies are based on very large data sets and essentially all conclude that on average conventional farming has 20-40% higher yields than organic.

From this yield-gap a host of other negative conclusions about organic farming are derived: lower yields need more land to produce the same amount of food, leading to the necessity of more land-clearance, causing o.a. biodiversity loss. It may even lead to the necessity for countries to import more food with a negative effect on their overall Green-House-Gas (GHG) emissions due to large scale additional transportation needs. Surprisingly, the above studies pay little attention to the positive impacts of organic/biodynamic farming, i.e.: soil health improvements by carbon sequestration in soil, which is essential for the arguments developed in the present study for the relationship: soil health – crop yield – Carbon Credits – farmer income. There is ample evidence for the opposing position, i.e., that organic farming leads to a negligible yield loss (Hewlett 2006 ^[15], Vasilikiotis 2000 ^[44], Muller *et al.*, 2017 ^[28]), or even to better yields after >5 years of organic farming practices (Rodale Institute 2019) ^[35]. Also, a number of studies demonstrate that soil health is improving under continued organic farming practices (Krause *et al.*, 2022) ^[18], which is essential because soil health relates to soil productivity. In general, GHG emissions and biodiversity loss is claimed to be lower in organic agriculture in many studies, and this paper offers a case study in Egypt to support this position. Farm-land soil in general can provide a positive Ecosystem Service when managed by organic farming practices. Organic-based food systems can be at par with conventional ones, if accompanied by a holistic approach to the entire food supply chain management (Muller *et al.* 2017) ^[28]. So, the paradigm “Organic agriculture cannot feed the world” has a number of elements worth reassessing. The other paradigm “Organic food is more expensive” is essentially supported by all published data, and at face value there appears to be little leeway to change this paradigm (e.g. see Ankamah-Yeboah *et al.*, (2019) ^[1]). But, it is important to realise that none of the published cost assessments take environmental damage by conventional farming into account. The True Cost Accounting methodology (TCA, WUR 2022) ^[45] monetizes all the damages done to the environment by the food production system. TCA readily shows that organic food has a lower production cost than conventionally produced food. Unfortunately, TCA needs a taxation system based on environmental damage done during food production, and this has proven to be very difficult to implement. Another parameter to consider in food price calculations is the net carbon footprint of food-stuff. None of the published studies considers the monetary value of carbon sequestration and of GHG emission avoidance by using compost as fertiliser (as used in organic farming). Both parameters can be monetized and therefore are relevant to computing the net cost of food production. Paustian *et al.* (2019) ^[31] reviewed the potential of soil carbon sequestration as a major climate mitigation strategy and concluded that between 3 and 8 Gt CO₂eq/year can be sequestered globally by proper farming practices (here interpreted to be organic farming). Referring to EU (2022) carbon emissions systems documents ^[10], this can be converted to a multi-billion Euro carbon credit market simply by proper farming practices. Including monetized Carbon Credits in food-production economics, opens the door to challenge the paradigm about the high cost of organic food. Therefore, the objective of this paper is to demonstrate that: a) long-term organic farming can bring crop yields at par with conventional farming, and b) that inclusion of carbon credits in the overall price of food produced can tip the economic

balance favorably towards organic food production.

In this paper we are particularly interested to demonstrate that carbon credits from farming have the potential to transform the agricultural sector. We will illustrate this potential through Egypt as a case history. In the case history, the positive effects of organic/biodynamic farming will be demonstrated as compared to conventional using a large number of indicators, including production costs ("DOC" trial). The overall economic assessment of organic/biodynamic farming is then expanded by inclusion of carbon credits. Finally, this assessment is upscaled to the entire farming sector of Egypt and it demonstrates that farmers in Egypt can produce the same volume of food at the same price, and also improve their lives by transforming from conventional to organic agriculture.

Materials and Methods

A new agronomic data set was created based on the 6-year Sekem "DOC" trial (i.e., the comparison of bioDynamic, Organic, and Conventional farming; Sabahy *et al.* 2024). The resulting data were then used as input for our cost analyses and for the carbon credit computations.

- The total cost (TC , US \$/ha) includes all farming operations, materials, irrigation, and energy cost. $TC = \text{Fixed costs} + \text{Variable costs}$. The production cost (PC , US \$/ton) was computed by: $PC = TC / \text{Crop yield}$
- Total return, or turnover (TR , US \$/ha) was calculated with: $TR = \text{Crop price (US \$/ton)} \times \text{Yield (ton/ha)}$. In this study the sales price differences of 20-25% between conventional and organic were ignored to create a level playing field in our assessment (Ankamah-Yeboah *et al.*, 2019). Net return (NR , US \$/ha) was calculated by: $NR = TR - TC$. All costs for the DOC trial are based on our own real expenses; no depreciation of existing equipment was included.
- The "Carbon Profit" computations include effects of Soil Carbon Sequestration, Tree planting, and GHG emission avoidances by application of compost and by switching from fossil-fuel to renewable energy. Cool Farm Tool (CFT) modeling was used to quantify and monetize net greenhouse gas emissions. The CFT method calculates both GHG emissions and removals associated with the production of an agricultural product. The CFT is based on the IPCC's 2019 refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- The total profit (TP , US \$/ha) was calculated using: $TP = NR + P_{CO_2}$, where P_{CO_2} refers to profit related to carbon sequestration plus GHG emission avoidance.
- The carbon market price per ton sequestered was determined based on the average selling price from 2016/2017 to 2021/2022.

A second dataset was generated to compare the profitability of Organic versus Conventional farming over a large area in Egypt. For this, data from a representative set of 30 conventional farmers in the various governorates of Egypt, and on statistical data on agricultural costs from the Ministry of Agriculture (Central Agency for Public Mobilization and Statistics; CAPMAS). Our own data collected over the many years from our associated organic/biodynamic farms were used in this analysis were merged with the governmental data for our profitability comparison. In this comparison we applied "True Cost Accounting" (TCA).

- True Cost Accounting (TCA) measures and values in monetary terms the external costs of the environmental impacts of food production (IFOAM 2021).
- For the assessment of environmental damage cost the TCA methodology described by Gemmill-Herren *et al.*, (2021) was applied.
- The same economic parameters as used in the DOC evaluation were used in the TCA analysis.

The DOC trial was carried out at the SEKEM farm (30.421 N and 31.635 E), in Egypt from 2016 to 2022. Design details and results of the DOC experiment have been reported recently by our colleagues (Sabahy *et al.* 2024). Here we use the yield results of two crops only: faba bean (cultivated October-April) and maize (cultivated May-September). The Conventional plots were treated to standard agronomic practices and fertilizer rates as recommended by the Agriculture Research Center, Ministry of Agriculture, Egypt. In the Organic and Biodynamic plots, compost was added at the rate of 24 ton/ha. The used compost has a pH=7.42, 36% (OM) organic matter, 21% organic carbon (OC), C/N=16. O and D plots also received Herbiofert, manufactured locally by SEKEM, at a recommended dose of 714 l/ha. The biodynamic plots additionally received a horn manure treatment of 357 g/ha (Bucher & Bucher, 2020) ^[4] as well as Silica @ 4.8 g/ha 3 times during the season. All plots were watered by drip irrigation. Standard soil analysis methods of Snyder (1896) ^[37], Black (1965) ^[3] were followed. The soil carbon sequestration (ton C/ha per year) under the effect of different farming applications was calculated from the differences over time.

Results & Discussion

Feed the world: Crop yield DOC

The effect of different farming systems during the 6-year trial on the yield of maize and faba bean crops is illustrated in Fig. 1. The use of chemical fertilizers for maize and faba bean crops at the beginning of agricultural seasons led to higher yields than in the other systems, which agrees with results reported by Dhillon *et al.* (2017). Fig. 1 clearly demonstrates that with the progression of time the Biodynamic and Organic yields start to out-perform the Conventional ones after 3 years.

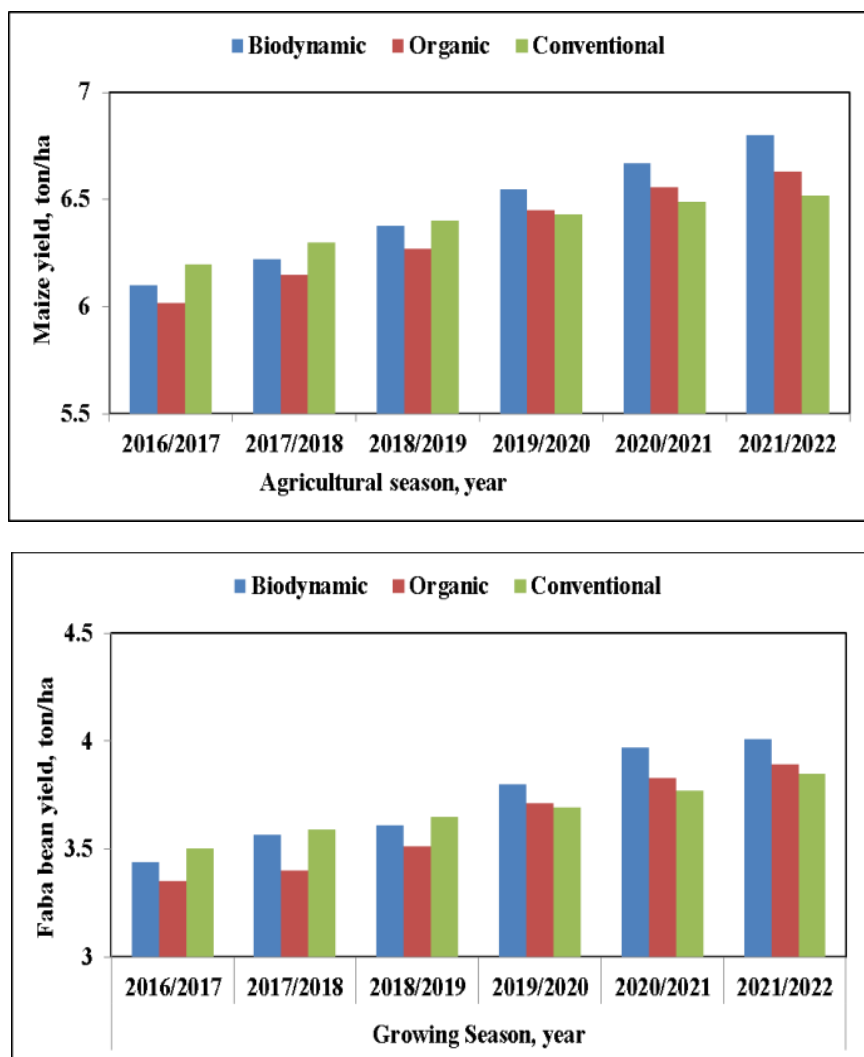


Fig 1: Yield of maize (top) and faba bean (bottom) crops under different farming systems (after Sabahy *et al.* 2024).

During the course of the 6-year experiment the soil-health, or fertility expressed by increase in soil carbon, improved steadily (Fig. 2) and this correlates well with the increase in yields. The present results agree with those published by several authors (Lori *et al.*, 2017 ^[23], Vasilikiotis, 2000 ^[44], Hirte *et al.*, 2018 ^[16], Timsina 2018 ^[41], and Krause *et al.*, 2022 ^[18]). Our results together with these findings suggest that the published yield gaps may have to be re-interpreted by looking into the details of the history and practices of the farms included in the large meta-studies (de Ponti *et al.*, 2012 ^[7], Clark and Tilman 2017 ^[5]). Not only the farm history, but also its size, climate zone, crop-types and soil management system all have their impact on yields. The present authors argue that lumping all data together in large statistical meta-studies may not be sufficient to conclude that organic farming cannot feed the world.

The DOC trial in Egypt also delivered new data for the discussion on carbon sequestration in soils. Figure 2A demonstrates that Biodynamic and Organic farming score

better than Conventional in this respect. The organic carbon sequestered in soil decreases slightly over time for conventional, but strongly increases for Organic and Biodynamic practices. This agrees with many studies (e.g. Krause *et al.*, 2020 ^[21] and Krauss *et al.*, 2022 ^[20]). This observation is very important: the gradual sequestration of carbon in agricultural soil is directly related to the gradual improvement of yields. Or inversely: the gradual reduction of soil carbon in Conventional farming is directly related to the diminishing of yields over the years which has caused an ever-increasing need for more artificial fertilizers. Soil erosion rate comparisons between organic and conventional farms have been reported (e.g. Reganold *et al.* 1987 ^[34]; Fleming *et al.* 1997 ^[13]; Arnhold *et al.* 2014 ^[2]) all concluding that organic farming leads to a reduction of soil erosion, and thus to protection of good agricultural soils. Clearly yields relate to soil carbon sequestration, and as will be demonstrated below, carbon sequestration generates more income for farmers.

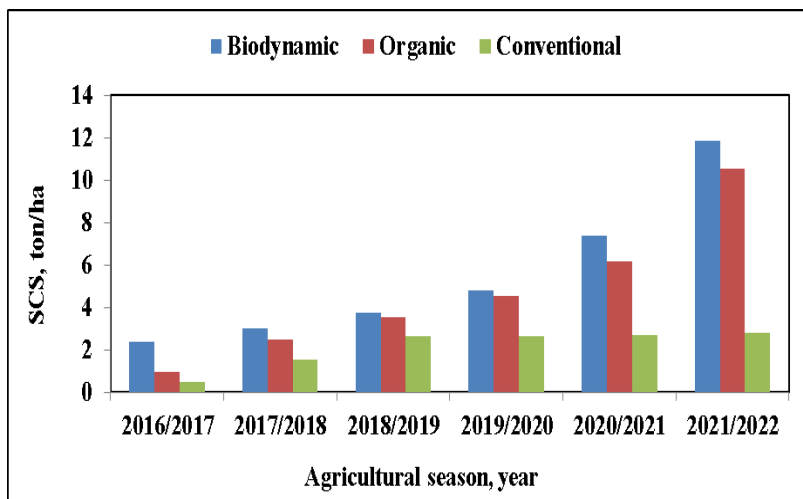


Fig 2: DOC trial results for Cumulative Soil Carbon Sequestration (after Sabahy et al. 2024).

We conclude from our DOC trial, supported by a significant number of other publications that Biodynamic/Organic farming has the potential to feed the world, but it takes a number of years for farms to reach their full yield potential.

Economic analysis: cost of food production DOC

For the economic comparison between the three farming systems applied in our DOC trial, we calculated production cost, total cost, total return, the net return, carbon profit total and total net profit. The cost analysis of the two crops maize and faba bean were computed as average values over 6 years.

Table 1 illustrates all financial costs divided over 5 main categories. It can be concluded that Costs and Return is not significantly different between the three systems. Assuming the unified selling price of the final products, the results showed that the use of the biodynamic system leads to a slight improvement in the Net Return of around 3%, because of the higher yields, which compensate for some of the higher variable costs. This result suggests that the paradigm “Organic Food” is more expensive, may not always apply in case of mature and highly experienced organic farming operations.

Table 1: Financial data for the 6-year DOC trial (After Sabahy et al. 2024).

Crop	Cost analysis	Farming system		
		Biodynamic (D)	Organic (O)	Conventional (K)
Maize	Variable cost, US \$/ha	155.93	156.33	145.62
	fixed cost, US \$/ha	855.66	840.85	757.29
	Total cost, US \$/ha	1011.59	997.18	902.91
	Total return, US \$/ha	1921.05	1910	1898.61
	Net return, US \$/ha	909.46	912.82	995.7
	Carbon profit, US \$/ha	323.38	274.93	-123.12
	Net profit, US \$/ha	1232.84	1187.75	872.58
Faba bean	Variable costs, US \$/ha	280.8	277.3	258.27
	fixed cost, US \$/ha	787.26	740.85	697.8
	Total cost, US \$/ha	1068.06	1018.15	956.07
	Total return, US \$/ha	2047.07	2025.18	2001.66
	Net return, US \$/ha	979.01	1007.03	1045.59
	Carbon profit, US \$/ha	274.873	233.6905	-104.88
	Net profit, US \$/ha	1253.883	1240.7205	940.71

The real difference in Net Profit between the three systems stems from the carbon profits gained in Biodynamic and Organic methods. Part of the carbon profit stems from soil carbon sequestration (SCS), and figure 2 convincingly demonstrates that D and O build up more soil carbon than C practices. Increase in soil carbon improves soil health and fertility, and thus positively impacts crop yield. Other important elements of the carbon profit are related to on-farm tree planting, and to avoidance of GHG emissions by using compost and by switching from diesel to solar powered irrigation pumps (for a detailed breakdown of the carbon credit scheme referred to in this paper, see: <https://eol.global/> and <https://economyoflove.net/>). Carbon sequestration and GHG emission avoidance evidently can play an important

role in the economics of farms. In the DOC trial SCS was more effective in Biodynamic/Organic than in Conventional (Fig. 2). Monetizing this SCS adds almost \$200/ha (10-20%) of profit for the organic farmer (Table 1), tipping the balance of profitability towards Biodynamic/Organic farming, even though we assume the food is sold at the same price. The results from our DOC trial would suggest that it is possible for farmers “to go organic” and produce crops with the same yield/ha (after a few years), offer them at the same market price, and make more profit thanks to SCS by transitioning from Conventional to Biodynamic/Organic practices. The results obtained are consistent a.o. with Sinha et al., (2010) [36] and Kumar et al., (2015) [19].

Case histories

A real paradigm shift in the public perception of Organic practices cannot possibly be achieved based on the 6-year, DOC trial only. A much bigger and real-life database is needed to make that claim. Therefore, the analysis is expanded by looking at the economics of different farming practices all over Egypt.

Carbon Credits to shift the Economic Paradigm:

Carbon credits schemes focus on monetization of positive effects of organic farming for the environment, whilst TCA schemes focus on monetization of environmental damages done to an ecosystem. Over the years, a taxation system needed for TCA implementation has proven to be rather difficult to implement for political reasons.

Carbon Credit schemes need a carbon trading market. Such markets do exist in various forms in different parts of the world, e.g. Verra (<https://www.verra.org>), Sylvera (<https://www.sylvera.com>) but in most cases such schemes are not set-up and too expensive for smallholder farmers to join. In Egypt, Sekem and the Heliopolis University have been successful in convincing the government to set-up a voluntary carbon credit market: the market was established in August 2024 (<https://moic.gov.eg/ar/news/1609>), and is easily accessible to smallholder farmers at very low cost.

For such carbon credit scheme to work, the carbon foot-print (negative or positive) needs to be assessed and certified. We have developed the necessary assessment and certification scheme, that is the foundation for the Egyptian Voluntary Carbon Market. We use the Cool Farm Tool (CFT), which computes the net carbon footprint of a farm considering: carbon sequestered in trees planted and in soil cultivated. Then, it considers GHG emission avoidances by composting organic farm waste and manures relative to land-fill dumping of the same amount of degradable organic matter; also GHG emission avoidances are computed for switching from fossil-fuel based to renewable energy. The basic relationships for carbon bookkeeping in our model are:

Sequestration: Soil: 3,5 tCO_{2eq}/ha.yr; this implies ~0,08wt% soil carbon sequestered/year in the top 15 cm of soil. Trees: 0,03 tCO_{2eq}/yr (one tree is assumed to sequester 1 ton over 30 years).

GHG emission avoidance/reduction: Composting avoids emissions of 0,6 tCO_{2eq}/ton compost; application of 20t compost/ha.yr implies 12 tCO_{2eq}/yr emission reduction. Renewable Energy 1.35 tCO_{2eq} /kW installed.

For one of our reasonably large farms of 339 ha, CFT computes 1187 tCO_{2eq}/yr soil sequestration. On that farm we have planted 190.000 trees sequestering 6333 tCO_{2eq}/yr. Application of 20t compost/ha.yr leads to GHG emission avoidance of 3462 tC et _{2eq}/yr. In total this 339 ha farm collects carbon credits of about 11000 tCO_{2eq}/yr, and assuming a market price of about US\$38/t, this represents about \$ 424000 of additional income for this large farm. Expressed per hectare, about \$ 1250/ha each year.

Switching to a second example, a typical smallholder farmer in Egypt cultivates 6,3 acres (2,6 ha), has some 280 trees for windbreaks and applies 50 t of compost per year. CFT models this activity to generate 47 Carbon Credits/year, generating US\$1805 /year in additional annual income (US\$286/acre), again assuming the modest \$38/credit, implying roughly a doubling of the farmer's earnings (compare Table 1).

Although this US\$694/ha each year does not seem a lot, this should be put into the perspective of Egypt with about 3

million ha in cultivated land. Therefore, the additional income based on carbon credits from farming in Egypt would amount to 1-2 billion Euros every year, simply by converting from conventional to organic farming. This really would present a paradigm shift!

Conclusions

We demonstrated in this paper that conversion from Conventional farming to Organic or bioDynamic farming practices will not impact the volume of produced food per hectare after 3-5 years of transition. The often-quoted yield-gap between conventional and organic farming appears to be related to the statistical handling of large datasets, which obscures the real underlying causes of the observed yield gaps. Based on our own field trials and comparable (better, longer) trials published in the open literature it can be concluded that organic farming yields are comparable to conventional ones, when considering "mature" organic farming systems, i.e. those farms in which soils have recovered from pre-existing soil fertility degradation. Yield-gaps do occur during the first 3-5 years of conversion from conventional to organic only.

The production costs for organic food can be demonstrated to be very similar to those of conventional. So, there appears to be no real reason for the reported higher price of organic food. Moreover, organic farming causes no environmental damage to soils, ecosystems, or surface waters, and no hidden costs have to be accounted for. On the other hand, conventional farming has serious hidden costs related to environmental damage. Monetizing such costs (True Cost Accounting) immediately results in organic produced food to be cheaper. An environmental tax system for environmental damage is needed to effectuate TCA.

Carbon credits generated through soil carbon sequestration, on-farm tree planting, and GHG emissions avoidances related to the application of compost instead of chemical fertilizers, adds to the potential profitability of organic farming. The necessary carbon credit market for smallholder farmers has recently been launched in Egypt.

The Ecosystem Services delivered by the soil of a production farm are significantly improved by switching to organic/regenerative farming practices.

In conclusion, this paper has demonstrated that the new paradigm for organic agriculture should be: "Organic farming can feed the world at a competitive price and is better for the environment".

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