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Organic arable farming and climate impacts

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- Organic farming is a growing industry where farmers can achieve higher prices but production costs tend to be higher
- Advocates of organic farming indicate several climate beneficial effects, however, scientific research surrounding these benefits are conflicted
- Organic farming practices have highlighted important best practices which could be incorporated into conventional farming to offer the most realistic balance between climate benefits whilst still providing sufficient food globally

What is organic farming?

Organic farming systems involve the production of agricultural products by using natural biological systems and holistic approaches with a focus on the avoidance of synthetic chemical inputs and importance placed in recycling nutrients. Other concepts of note within organic farming is a focus on the interaction of livestock directly with crop grazing systems alongside rotational grazing to help improve soil fertility via natural animal-based fertiliser addition and the ban on synthetic nitrogen application. Crop protection chemicals (e.g. pesticides) are only utilised if they are natural rather than synthetic with alternate strategies such as mechanical weeding and pest control measures suggested as replacements. A potential contradiction in this area involves the use of tillage-based weed control measures which are prevalent in organic crop management. These have been noted to have detrimental climate impacts, despite UK organic certifiers principles including "use of processes that do not harm the environment". In organic farming, the use of genetically modified organisms (GMOs) and products made using GMOs are banned, despite this, however, in EU regulations products derived from GMOs if of a veterinary medicinal nature are allowed, which again acts as a prominent contradiction to organic principles. Whilst organic farming standards are directly enforced by each farm's registered certifier (via bookkeeping, regular inspections and the incentive of certification leading to higher produce sale prices) this does not inherently make such practices and principles organic farming specific, many conventional systems can and are utilising similar practices (including use of crop rotation strategies and reducing chemical applications).

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Organic food is a multi-billion pound industry for the UK with most recent figures suggesting a value of £2.45 bn annual sales and 4.5% growth of the last 8 years (accounting for around 9% of the UK gross output based on 2018 figures). Globally organic food was noted as the fastest-growing food sector in North America and Europe based on 2016 data and accounts for between 1 - 2% of all farmland, with the largest regional area of coverage being 8.5% in Oceania regions surrounding Australia. In the UK organic food growers must be registered with a government-approved certification body of which there are currently 8 nationally, with the 'Soil Association' being the largest certifier by far. Previously all organic food standards were overseen by the UK register of organic food standard (UKROFS) which ensured standards complied with EU and international equivalents. In the follow up to Brexit, new laws and standard changes will become active on the 1st of Jan 2021. These include the requirement for producers to undertake new registrations to be applicable to trade abroad with around 8% of the UK's organic food currently being exported.

Climate benefits

A vital advantage noted by supporters of organic farming is the increased climate benefits associated with this strategy compared to conventional farming practices, however, this area is under significant debate with evidence to support both sides of the argument.

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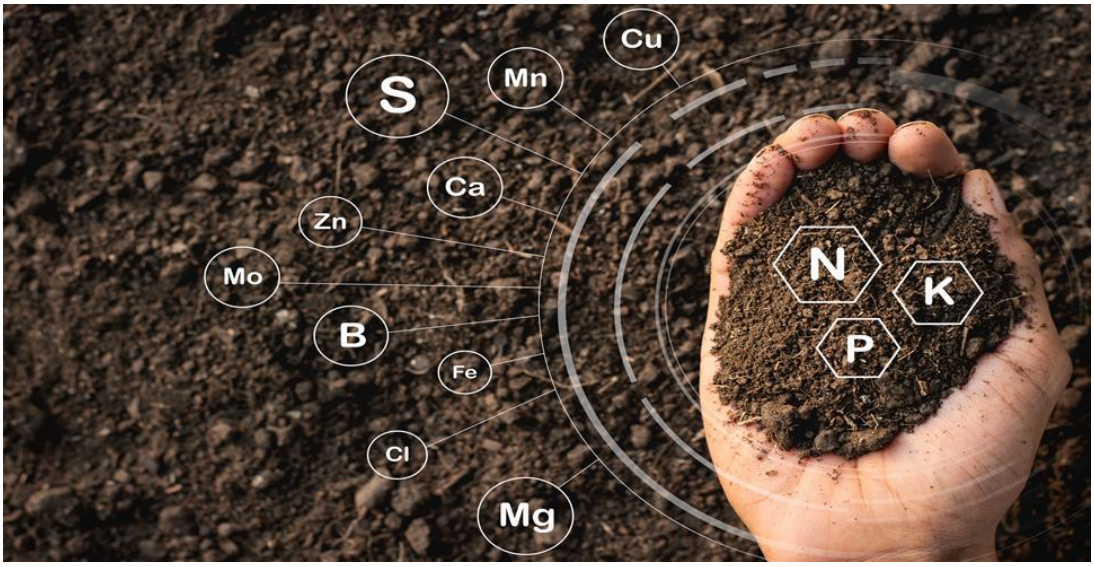
Nitrogen and chemical inputs

A benefit regularly suggested in association with organic farming when compared to conventional farming is the reduction/elimination of synthetic chemicals and nitrogen (N) fertiliser use. Nitrogen is a vital nutrient for plant growth but different forms are susceptible to different transformations which can lead ultimately to greenhouse gas (GHG) emissions in the form of nitrous oxide (N_2O). Organic farming utilises manure, compost and atmospheric fixation via leguminous crop rotations (green manure) as alternatives to synthetic N fertilisers with certain studies demonstrating lower emissions from manure on direct comparison to N fertilisers. Fertilisers act as a change in direct soil inputs and affect soil nutrient cycling system outputs (emissions of N_2O) but on top of this, the industrial production and transport of fertilisers and synthetic plant protection chemicals inherently requires energy and, therefore, produces GHG emissions. In a report produced by the 'International Federation of Organic Agriculture Movements' (IFOAM) it was predicted that the total conversion of the EU to organic farming would lead to an 18% reduction of the total EU agricultural emissions produced, whilst others have noted that the production of N fertilisers utilises ≥1% of the total annual fossil fuel energies and would be equivalent to 90 million tonnes of fuel. Alongside this (whilst it is difficult to calculate as peer-reviewed study figures are largely outdated) the emissions related to plant protection chemical productions have been suggested to be around 1/10th of the level of N fertiliser production, acting as another emission source where organic farming has the potential to achieve emission reduction via their exclusion (though it should be noted that organic farming still allows certain chemicals it considers to be 'natural' and these inherently have emission values associated with their production).



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Nitrogen fixation via leguminous green manure is another route where organic gains can be made with previous studies suggesting that incorporating more leguminous cover crops in off-seasons (to not affect crop production for food) could supply an excess amount of nitrogen globally above what is required from synthetic N fertilisers.

Nitrogen and chemical leaching

Nitrogen leaching is an important climate consideration as it leads to indirect emissions of N_2O. Nitrogen leaching in organic farming has been indicated to be lower than conventional when considering total land area N leaching levels. This is likely largely due to reduced N inputs with some indications that the forms of N in organic fertilisers are less susceptible to leaching due to lower levels of soil mineral N being present. Where chemical leaching and pollution is concerned (e.g. from pesticides) organic practices prohibit the use of the majority of these and as such their leaching and presence in surrounding waterways in the vicinity of organic farms is likely to be much lower though this is a currently understudied area of organic farming.

Yield differences

Yield is an important climate factor in farming as a key measurement is often the amount of product produced compared to the greenhouse gas emissions associated. Ideal systems supply sufficient food for the population with the lowest emissions outputs. Organic farming emissions are suggested to be lower but equally yields are generally perceived to be lower particularly in cereals, however, fodder crops, legumes and perennials demonstrate generally higher yields than conventional farming equivalents. One aspect of these lower yields in organic farming may be linked to the fact that most major crop varieties have been specifically bred for high-input systems which are not present in organic farming. As such a significant amount of research is currently underway towards selective breeding of food crops towards organic farming challenges such as insect and disease tolerance and improved yields under lower input. In the future, this could reduce yield gaps between conventional and organic farming. Whilst yields appear reduced within organic farming certain studies claim that when crop dry matter is compared with conventional comparisons these yield differences tend to disappear, suggesting water content to be a factor in higher perceived yields in conventional systems. In these cases, water swelling may increase perceived fresh/wet weight increases and actually be acting to "dilute" the available nutrients. A key aspect in current conversions to organic farming is improved sale prices with systems demonstrating that, for farm profitability, reduced yields are often outweighed by improved sale prices.

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Soil, carbon and other impacts

Soil organic matter (SOM) measurements are often used as a generalised indication of soil health as SOM plays roles in structure, water retention, productivity and soil erosion. One aspect of SOM is the soil organic carbon levels or SOC with papers suggesting increasing SOC reduces climate change impacts by storing carbon in soils. Organic farming is generally associated with higher SOM levels which should equally increase SOC levels providing increased climate benefits by sequestering carbon at improved levels compared to conventional farming. Furthermore, organic farming is regularly noted to require lower energy inputs per product unit for most arable products (though in some fruit and vegetable products such as potatoes this is not seen). Energy input is largely associated with reduced levels of fossil fuels compared to conventional where these are required to produce and transport chemicals and fertilisers.

Counterpoints to organic climate benefits

Nitrogen and chemical inputs

With the way systems operate currently many organic farms are reliant on the waste output from non-organic farms as a source of N, P and K due to lower livestock stocking densities leading to reduced manure fertiliser outputs from organic systems only. Furthermore, when comparison studies removed organic farms which relied on being supplied with conventional manure it was found that organic yields reduced up to 34% on average compared to conventional. This is particularly important for modelling a fully organic future as this would lead to the loss of conventional manures available to supplement crop needs. In a recent study comparing 46 paired organic and conventional systems, it was found that 25 - 110% more land was required (figure 1) to achieve equivalent yields. This increased land use is likely

to be due to the reliance on manure which releases N slowly and in response to particular environmental conditions rather than being readily available and directly able to be taken up by plants as in synthetic N fertilisers. This leads to mismatches of N availability when the crops have a high demand causing lower crop growths and afterwards unutilised N may increase eutrophication and acidification of soils. Whilst N levels are a huge factor in climate impacts of agriculture, improving the efficiency of application could be a more precise way to control the emissions associated and any over-application issues could be resolved by using soil condition mapping and variable rate technologies. Such systems are inherently more difficult to utilise in organic farming as manure itself is variable in nutrients depending on its source and its breakdown can be slow, variable (based on environment, water, temperature etc) and difficult to model to ensure N needs are met whilst avoiding overapplication of phosphorous. Furthermore, N fertiliser application in some papers is suggested in fact to lead to lower emissions of GHGs than manure/compost equivalents due to more favourable conditions being present in manure environments for microbial detrimental N_2O production.

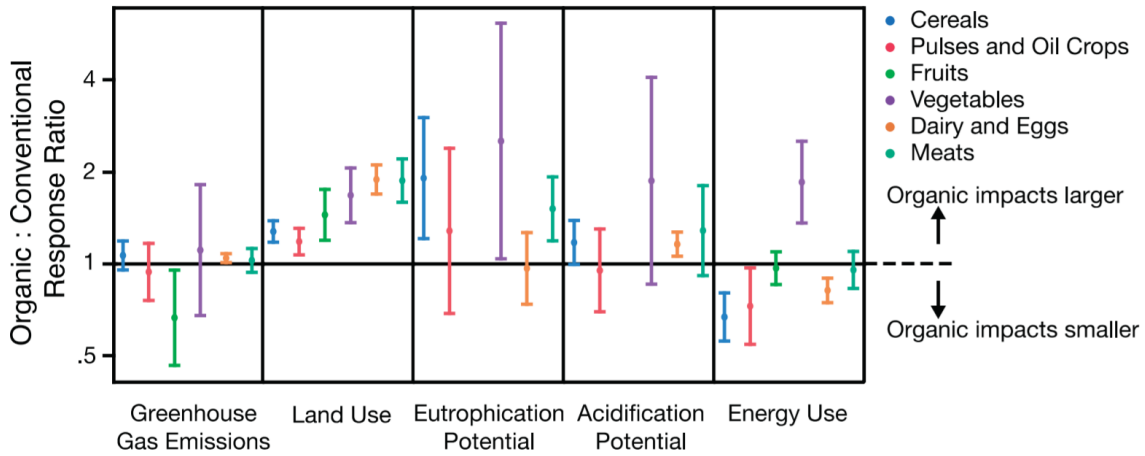

Figure 1 Ratio of the environmental impacts of organic and conventional food production systems >1 = negative impact of organic practices <1 = positive impacts of organic practices

Where nitrogen fixation via cover crops (green manure) is concerned the previous study (above) may have overestimated N level fixation achievable as assumptions are made that 100% of arable land available is capable of supporting another winter leguminous crop. This assumption doesn't factor in high productivity pasture systems which produce multiple food crops, those which were simply unsuitable for leguminous growth environmentally during off-seasons and the trend for ever-increasing global food demands which will lead to a constant

need for increased N availability. Furthermore whilst green manure is often a favoured strategy of organic systems due to the need to supply N without N fertilisers the integration of leguminous crops into conventional farming systems are common and can inherently reduce their need for N fertilisers.

Nitrogen and chemical leaching

Nitrogen leaching in organic farming practices is generally found to be equivalent to or higher than conventional farming when figures of leaching per unit of product are considered. This increased leaching in organic systems has in some instances been associated with the slow release of N leading to excess' when crops are not present or have lower requirements. A trend with regards N leaching appears to be that regardless of organic or conventional farming systems, cover crop incorporation has the biggest impact on reducing the leaching effects. Furthermore, certain studies have noted that organically certified chemicals can in some instances be more harmful than many conventionally applied equivalents due to requiring excess applications to be effective, removing some of the perceived benefits of organic systems.

Yield differences

Generally, across several comparison studies, the emerging trend suggests that organic farming leads to lower yields in comparison to conventional systems. Whilst this may not be the case in certain crop scenarios reductions appear to range between 20 – 40% on average. In many instances, product yields can be reduced further due to strategies which require the inclusion of rotations of non-harvestable green-manure crops that lead to periodic production losses as leguminous crops are grown simply to return N to the soil offering no saleable yield outputs. For these reasons, organic farming would require larger land areas to produce the same crop yields requiring changes in land usage for example from forestry towards increased organic arable land which would remove vital CO_2 sequestration potentials and cause net increases in emissions. It is due to this lower yield trend that many analyses of organic farming note higher emissions are present per product unit demonstrating a reduced efficiency in organic farming to produce the same levels of a product as conventional farming without detrimental or equivalent climate effects. Focusing on increasingly higher yields as is often the case in conventional systems can also be beneficial for the environment as achieving higher yields with less land could free up land for specific ecosystem services, such as forested areas and wildlands which can improve biodiversity and benefit carbon sequestration. Organisations and researchers highlighting organic farming as an applicable alternative tend to note that its future is heavily reliant on global changes in human diets (towards reducing overconsumption and lowering red meat) and reductions in currently huge levels of food

wastage to account for such lower yields. Where the breeding of 'organic' specific crop cultivars are concerned as noted above these breeds could provide equal benefits to reducing N input and chemical applications if they were incorporated into conventional systems and as such shouldn't be considered an organic specific benefit.

Soil, carbon and other impacts

Whilst SOM and SOC are known to be beneficial measurements when considering soil health and certain environmental impact potentials, they can be highly difficult to measure effectively. Many individual studies which are included when comparing organic and conventional farming lack sufficient information on soil management histories and historic SOC levels, therefore, even when measurements are taken true changes may be skewed. Certain conventional farming strategies, such as the inclusion of diverse rotational crops, have been demonstrated to lead to increased SOC levels when compared to certain organic strategies, such as alfalfa green manure but reduced when compared to other organic strategies such as cattle manure applications across long-term studies. This suggests that context needs to be considered when comparing conventional and organic farming and that incorporation of "good practices" which are often common in organic farming (such as diverse rotation strategies) into conventional systems could be another route to mitigate emissions. In many instances, organic farming leads to tillage practices due to the need to control weeds without utilising chemicals. This can disturb SOC accumulation and has repeatedly been noted to be linked with detrimental soil management in regards to climate change and release of carbon stores. Furthermore, many argue that SOC improvements due to applied animal manure/compost may just act as a re-arranging of carbon rather than a reduction as the fields where the cattle themselves graze or where fodder is grown may simply be seeing a balancing reduction of SOC (though little research has considered this to date). Finally, organic farming uses compost and manure which are susceptible to decomposition leading to the release of CO_2. CO_2 release is further increased as organic farming practices improve soil pore space, eases root penetration and therefore, increases the flow of water and gases which also boosts microbial activity all of which act to boost CO_2 respiration. Whilst this is a potentially an important consideration for overall GHG balances of conventional and organic practices CO_2 has a much lower direct impact than N_2O.

Summary

This brief overview comparing organic and conventional farming environmental effects highlights the difficulty of definitive assessments in this area, with many grey areas present which require further specific research and targeting. There appear to be certain food products where organic farming demonstrates more beneficial climate impacts and others

where conventional systems show higher benefits. Much of the research to date relies on the meta-analysis of conventional vs organic practices and often the management practices are entirely different between compared studies and data matching may be skewing results. Also due to the relatively low uptake of organic farming globally, most research which attempts to scale organic farming up is reliant on modelling which requires predictions and assumptions which may not act as a true representation of large scale organic farming's true functionality. Much of the focus currently has been on directly comparing these two strategies, with very little research being performed into comparing organic specific practices to help determine which strategies are having the biggest impacts. This knowledge could help to better compare organic with conventional strategies more fairly, and even indicate which strategies conventional farming could employ towards further improving aspects such as ecosystem services (e.g. improve biodiversity, carbon sequestration) whilst maintaining its benefits of higher yields and improved emission outputs per product. Organic farming has a significant level of public support and is often perceived (particularly in Europe) as the most sustainable form of farming despite a lack of strong evidence either way. It is important to note, however, that organic farming globally is heavily reliant on direct subsidies (particularly surrounding farm conversion periods) to make up for yield losses (which are largely confirmed by scientific research) and to encourage environmental benefits (which are currently controversial and disputed across scientific research). As such there could be strong arguments towards re-directing such subsidies towards farmers implementing specifically beneficial farm practices (e.g. low or no-till, cover crops) incentivising conventional farmers to incorporate these. As conventional farming accounts for the majority of agricultural practices uptake of such a strategy, even if individual practices produced minimal environmental gains, could have far higher overall impacts on the sector as a whole.