INDUSTRIAL OR AGRO-ECOLOGICAL FARMING? PERFORMANCE INDICATORS IN THE UK

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Abstract

This paper examines the performance of conventional, high-input 'industrial' farming and agro-ecological smallholding across seven different indicators of performance: 1. Productivity per unit area. 2. Productivity per unit cultivated area. 3. Nutritionally necessary productive capacity. 4. Productivity per unit labour. 5. Productivity per unit greenhouse gas emitted. 6. Productivity per unit fossil energy use. 7. Biodiversity. Productivity is measured in terms of gross food production, energy and protein. Data are taken from UK average figures and specific farm productivity figures on the basis of two 'ideal-typical' farms of their type: a 100ha mainly arable farm and a 6ha horticultural smallholding. It's found that the industrial farm is more productive on a unit area and labour basis, but that the agro-ecological farm is adequately productive in terms of nutritionally necessary productive capacity. The agro-ecological farm is more productive in relation to greenhouse gas emissions, fossil energy use and biodiversity. Thus each farm type offers specific forms of productive efficiency – neither is the most 'efficient' in any absolute sense. The paper discusses data limitations and policy implications.

Introduction

A counter-movement to industrial farming is emerging in Britain and other affluent countries. Influenced by agro-ecology, permaculture and allied ideas, it emphasises a diverse, small-scale, mixed farming involving the biological cycling of nutrients, the synergistic cultivation of annual and perennial plant crops along with livestock, and the production of diverse unrefined farm products for local use. But it doesn't command attention from policymakers, and is frequently derided by proponents of industrial agriculture as a utopian distraction from the serious business of growing enough food to feed a growing human population.

Many of us involved in agro-ecological smallholding are inclined to think on the contrary that our methods *can* deliver on productivity grounds, as well as outperforming industrial farming in environmental and public goods. Indeed, we suspect that industrial farming involves its own utopias, while drawing down on natural capital at the expense of future generations. However, there isn't a great deal of data available to help us make our case. Various studies have compared 'conventional' with organic farming, but organic farming is not the same as agro-ecological smallholding, and in many respects conforms more to the industrial farming model. By contrast, agro-ecological smallholding in affluent countries does not attract significant research interest.

This paper is a modest attempt to help fill that gap by comparing industrial farming with agro-ecological smallholding in the UK across a number of relevant performance indicators[1]. I can't pretend that my analysis is rigorously scientific – the data are patchy and, as a full-time farmer, I'm short of time. But I hope my results are plausible and informative enough to prompt interest and further refinement. The data and assumptions are presented in the Appendix, so the robustness of the analysis can be tested using other datasets.

Industrial farming and agro-ecological smallholding compared

My analysis is based upon comparisons between two 'ideal-typical' examples of the industrial farm and the agro-ecological smallholding, which are described as follows:

> *The Industrial Farm* is a lowland unit of 100ha, growing 35ha wheat, 23ha barley, 11ha oilseed rape, 3ha potatoes, 23ha grass ley with a grass-fed beef herd and 5ha left uncultivated. The

[1] Here I focus almost exclusively on productivity indicators; I look at wider social and economic factors in Smaje (2011).

herd provides a little fertility for the arable crops, the remainder (about 90%) being purchased in the form of ammonia-based fertiliser. Synthetic pesticides are also bought in. The unit employs two full-time equivalent (FTE) workers, and the farm work is done by a 6 tonne tractor with associated machinery, burning fossil diesel. The products of this farm are sold to a distributor who ultimately supplies supermarkets.

The Agro-ecological Smallholding is a lowland unit of 6ha. About 65% of the unit comprises permanent pasture (and other herbaceous perennials such as comfrey) grazed rotationally by sheep. The pasture in fact is an orchard understory – above the sheep are apple, pear, plum, chestnut, walnut and hazelnut trees. In the remaining 35% of the unit annual herbaceous vegetables are grown using organic, minimum tillage methods: of this 35% portion, about 20% is down to a fertility-building leguminous ley, 20% is down to potatoes, 10% is down to wheat and the remaining 50% grows a variety of vegetable crops in rotation, such as onions, carrots, parsnips, sweetcorn, beetroot, cabbage, lettuce, squash and beans. Small quantities of mushrooms and honey are also produced. All fertility on this farm is generated onsite through leys, composting and animal manures (the sheep are folded at night on the leys), and pest control is managed organically with no synthetics bought in. The farm work is carried out mostly by people – 2.5 FTE on the 6ha – with the help of a 100kg two wheel, petrol-burning tractor, and various other small hand and power tools. The products are sold locally by the farm van delivering grocery boxes to local residents door-to-door.

There may not be many real industrial farms that look much like the one I've described; its components were chosen because they correspond roughly with the mix of land uses in UK agriculture as a whole[2]. Productivity data for this farm are taken from 10 year average DEFRA statistics[3].

The agro-ecological smallholding is based upon – but not entirely identical with – my holding in Somerset[4]. Productivity data are taken where possible from my own measured yields in 2009/10 (which were probably rather lower than their achievable potential). In cases where my system is not yet in full production such as the fruit and nut trees, I've used average productivity figures derived from the literature (see the Appendix for details).

Obviously, it would be possible to construct other comparators – and in particular, it would be possible to adjust the agro-ecological holding either towards more staple crops or towards more diverse perennial cropping – but the cases I've chosen seem reasonably plausible exemplars of their type. One point worth making is that real world examples in both cases would probably involve a more complex profile of livestock, but since livestock other than non-dairy ruminants tend to eat food that could otherwise be eaten by people, restricting the comparison to beef cattle and sheep helps to keep the energy pathways simple. It also, incidentally, biases the analysis in favour of industrial farming, and this is something I have tried to do throughout the analysis. Any attempt to quantify something as complex as a farm inevitably involves oversimplification, so I've tried to mitigate the effects of this by systematically biasing my results in one direction (further details in the Appendix). If agro-ecological smallholding still emerges with any credit, then this should give us a sound basis on which to infer its merits.

The Performance Indicators

I propose to examine farm performance across five different indicators, as follows:

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[2] DEFRA (2011)
[3] DEFRA ibid.
[4] This is described in more detail in Smaje (2010a; 2010b). See also www.vallisveg.co.uk

Productivity per unit area. The basic function of farms is to produce food. Our industrial farm produces five types of food, whereas the smallholding produces about sixty, depending on how you define a 'type'. One way to compare them would be to add up the weight of food produced by the two farms. But of course not all foods are nutritionally equal. Energy and protein are two key nutritional components that human bodies need, and which industrial farming is good at producing. We may find that the mixed smallholding produces relatively more weight of food and relatively less energy and protein: most of the residuum would probably just be water and roughage, but it may also contain more useful things such as vitamins and trace nutrients that are not so common in the five industrial farm products, a point which is worth bearing in mind. In theory we could quantify this in a whole series of tables nutrient by nutrient, but perhaps it's simpler to assume that the smallholding can produce all the minor nutrients we need – the question is whether it can produce enough of the macronutrients.

In order to compare like with like, we obviously need to look at the productivity per unit area of land. There are some complications here, which we'll come to later when we look at productivity per unit area of cultivated land and nutritionally necessary productivity, but the basic principle is fairly obvious.

Productivity per unit labour. I also enter into the dragon's den of industrial farm productivity by looking at productivity per unit labour. It seems clear which farm is likely to perform better on this indicator, though I shall argue that things are a little more complicated than they might seem. We shall also need to look at the implications of the two farms' labour profiles in the wider labour market.

Productivity per unit of greenhouse gas (GHG) emitted. I won't rehearse all the arguments about climate change here – I'm just going to assume it's a good thing to reduce GHG emissions whenever possible (the UK government has legally committed to reducing GHG emissions by 80% by 2050, and since agriculture is the second largest emitting sector[5] it seems reasonable to suppose that it'll have to reduce its emissions severely in the coming years). In my calculations, I've considered the following sources of agricultural emissions:

- On farm CO_2 emissions from energy embodied in machinery manufacture
- On farm CO_2 emissions from petrol/diesel use
- Off farm CO_2 emissions from the synthesis of agro-chemicals
- Off farm CO_2 emissions from petrol/diesel use in getting farm products to the point of consumption
- Methane emissions from ruminants
- Nitrous oxide emissions from the application of manures and nitrogenous fertilisers

Farming can also act conversely as a potential sink for GHGs. However, the research in this area is controversial. Tree and other perennial crops sequester carbon, though the final accounting does depend on the fate of the trees. Carbon can also be sequestered in soils, but only until the soil reaches an equilibrium of soil carbon. Adding compost to cultivated soils can help build soil carbon and thereby sequester carbon. There is evidence to suggest that ploughing releases CO_2 from the soil, whereas zero or minimum till techniques tend to help accumulate it – this is one of the reasons why the pasture in our agro-ecological holding is permanent pasture rather than a more 'productive'

[5] UK Greenhouse Gas Inventory (2011)

ryegrass ley. However, the evidence on this point is contradictory, and it may be unwise to assume that undisturbed soils in the UK act overall as carbon sinks[6].

For the purposes of this analysis I'm going to assume that there is a carbon benefit in tree crops and compost application, but no carbon benefit to reduced tillage (the latter assumption I suspect being fairly generous to industrial arable farming). Another probable act of generosity to industrial farming is my assumption that nitrous oxide emissions occur in simple proportion to the amount of nitrogen added (in reality I suspect that the nitrogen pathways on the agro-ecological holding involve relatively less denitrification than on the industrial one). Finally, I assume that the only emissions in transporting the produce to the point of use occur in relation to fuel use (ie. I assume that supermarket units have zero emissions).

Productivity per unit energy use. Fuel use is associated with GHG emissions, and so has been considered as part of the previous indicator. However, it's also a non-renewable resource, so on the face of it the less use we make of it the better. Opinions in the peak oil debate vary from those who think the declining availability of fossil fuels is going to involve a mildly inconvenient energy transition over the next century or so (Smil, 2010), to those who think that it will spell the end of civilisation as we know it (Duncan, 1996). Without necessarily taking a position in this debate, it seems to me that the choices in agriculture are starker than in other areas of energy use. Whereas fossil fuel power stations can at least to some extent be replaced by nuclear or renewable options, there are no very convincing substitutes currently available in the farm sector for the diesel that powers tractors and the coal or gas that feeds the synthesis of fertiliser[7]. So the supply of agriculturally useful energy is probably set to diminish in the foreseeable future, while at the same time the human population will continue to grow for some time to come, suggesting that the energy transition is likely to be a bumpy one at best. Adopting agricultural systems with high non-renewable energy productivities therefore seems sensible [8]. It's worth noting that there may be a trade off between productivity per unit area and productivity per unit fuel use. Advocates of industrial farming often invoke unit area productivity to suggest that organic or extensive farming is incapable of 'feeding the world' without extending the margin of cultivation. Perhaps the fact that they invariably consider this a bad thing reveals something about how they really view the environmental consequences of their favoured methods (it may after all be the case that 'land sparing' agricultural intensification is less ecologically benign than 'land sharing' agro-ecological farming[9]). The fossil energy dependence of industrial agriculture, by contrast, is rarely mentioned, perhaps reflecting the techno-utopian faith of its proponents that another energy source will be found. But it's worth remembering that much of industrial agriculture's productivity comes from non-renewable energy resources. Therefore, even if it's true that agro-ecological farming can't 'feed the world' it's still logical to shift production to high fuel productivity methods wherever possible in order to target non-renewable resources tightly to those places where they are absolutely needed.

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[6] DEFRA (2003; 2007)

[7] Apart from human/animal muscle and biofixation. Vaclav Smil – an energy expert who is in no way an advocate of agro-ecological farming – is dismissive of the future prospects for much-touted alternatives such as electric vehicles and biofuels (Smil, 2010), and also asserts that the Haber-Bosch process (the energy-intensive, fossil-fuel based method by which most nitrogen fertiliser is synthesised) "is not going to be displaced any time soon" (Smil, 2001: 218).

[8] Unless we decide to ignore the welfare of future generations because we think they can better take care of their own problems, as Steward Brand (2010) has recently suggested. Only those generations will be able to judge whether this view is humble, as Brand thinks, or merely irresponsible.

[9] There seems to be little empirical data available to elucidate this point – but see Perfecto and Vandermeer (2010) for one suggestive analysis.

Energy use for the two cases is calculated on the basis of,

- energy embodied in machinery
- direct on-farm fuel use (diesel/petrol)
- indirect energy use in agro-chemical synthesis
- fuel use in delivering produce to its point of consumption

Biodiversity. Biodiversity is a property of relationships within natural and farmed ecosystems, which defeats simple attempts at quantification. Nevertheless, biodiversity is crucial for the sustainability of any farm system. In the absence of obvious quantitative indicators I restrict myself to a few general points below about the effect of the two different farm systems on biodiversity.

Results and Discussion

We now turn to the data across our five dimensions of performance.

1. Productivity: Table 1 indicates gross food productivity per unit area.

Table 1: Food productivity per unit area

	Food produced ($kgha^{-1}$)	Energy produced ($MJha^{-1}$)	Protein produced ($kgha^{-1}$)
Industrial farm	5,700	67,800	539
Agro-ecological farm	9,800	19,800	153
Ratio	0.58	3.43	3.53

The agro-ecological farm produces more gross weight of food than the industrial farm (and as I mentioned above we shouldn't forget the good nutritional stuff bound up in the difference), but lags far behind the industrial farm in its provision of energy and protein – at first blush, perhaps, confirmation of the industrial farm's superior credentials for 'feeding the world'. However, we're not comparing like with like in the specific sense that most of the industrial farm (72%) is devoted to the cultivation of herbaceous edible annuals, whereas only a small part (about 27%) of the mixed smallholding is, and around 80% of the macronutrients that the smallholding produces come from this 27%.

The smallholding devotes so little area to herbaceous annuals for various reasons to do with biodiversity, labour, GHG emissions and fuel use, but also because it uses the non-cultivated part of the holding as a source of fertility for the annual crops. So the smallholding has adopted a land hungry method for generating fertility, whereas the industrial farm has adopted an energy hungry method by buying in synthetic fertiliser (which I assess at a generous 40 $MJkgN^{-1}$ total life-cycle energy usage). If we take an agnostic position on whether the land or energy intensive approach is best, it would be pertinent to compare productivity of herbaceous annual crops per cultivated area for the two cases, which is shown in Table 2.

Table 2: Productivity of herbaceous annuals per unit cultivated area

	Food produced ($kgha^{-1}$)	Energy produced ($MJha^{-1}$)	Protein produced ($kgha^{-1}$)
Industrial farm	7,800	93,500	742
Agro-ecological farm	29,400	54,400	489
Ratio	0.27	1.72	1.52

The performance gap on the macronutrient front has greatly narrowed in Table 2, though the industrial farm still outstrips the agro-ecological farm. It's tempting to excuse the agro-ecological farm by pointing out that its rival is using the full might of modern science and technology to produce only four macronutrient-rich crops, whereas the smallholding is using essentially allotment gardening techniques and a small rotavator to grow a wide range of crops (including such macronutrient embarrassments as lettuces and French beans) and still manages to grow nearly 70% of the protein and 60% of the energy as the industrial farm.

That excuse won't wash if the agro-ecological farm can't produce enough macronutrients. But how much is enough? There's no doubt that ammonia-assisted cereal farming can produce a lot of food – much of it gets fed to livestock or exported, which we may or may not judge to be a good thing. But supposing we wished to move towards a farm system with a greater role for agro-ecological smallholdings – could these provide enough food? A simple, if perhaps simplistic, way to check this is to apply the figures from Table 1 to national population and land use data. So, assuming very crudely that there are 61 million people in the UK, all requiring 10,500KJ (2,500 calories) of food energy and 50g of protein per day, and that this needs to be grown on the extant 12.1 million hectares of farmland (excluding rough grazing), we can generate the following table:

Table 3: Population nutrient productivities on existing UK farmland

	Energy productivity (persons)	Protein productivity (persons)
Industrial farm	214m	358m
Agro-ecological farm	62m	101m

This table is obviously questionable in many respects, but it does provide some *prima facie* evidence to suggest that a country of agro-ecological smallholdings generating only biospheric fertility onsite might be able to feed the UK population, with a narrow margin in the case of energy and a comfortable one in the case of protein. Not all UK farmland may be suitable for this kind of smallholding with its mix of land uses (although its extensive character creates some buffering), and of course in the future the farm system will have to deal with a rising population, possibly swollen by climate change refugees, and the effects of climate change itself. Certainly, I'm not suggesting that all farmland should be turned over to agro-ecological smallholding. However, these data do call into question lazy assumptions about the inadequacy of agro-ecological productivity. If we opt for intensive agricultural production using non-renewable inputs in order to produce more meat or food for export, then this is something we can choose to do. But that isn't an argument for persisting with industrial farming as a central tenet of agricultural policy – particularly in view of the health effects of excessive meat consumption and the damage caused to indigenous agricultures by food exports dumped on international markets. The truth is we could satisfy most of the nation's nutrient needs with a large-scale shift to agro-ecological farming. This would greatly reduce the use of non-renewable inputs, allowing them to be tightly targeted to where they're really needed.

Labour productivity: Let's now look at the labour implications of the two systems. Assuming 2FTE workers on the 100ha industrial farm and 2.5 on the 6ha smallholding gives us labour inputs of 0.02 $FTEha^{-1}$ and 0.4 $FTEha^{-1}$ respectively, which are applied to our productivity values in Table 4.

Table 4: Food productivity by labour input

	Food produced (kgFTE^{-1})	Energy produced (MJFTE^{-1})	Protein produced (kgFTE^{-1})
Industrial farm	392,000	4,677 ,000	37,000
Agro-ecological farm	23,000	47,000	370
Ratio	16.8	98.7	101.2

To put these figures another way, feeding the current UK population of 61 million at these levels of labour productivity would require something in the region of 70,000 industrial farmers (about 0.2% of the working age population) and something like 4.5 million smallholders (about 12% of the working age population).

Clearly, on labour productivity, industrial farming is streets ahead. Does that mean that a farm system in which agro-ecological smallholdings predominate is unviable? Probably yes, within the parameters of the present economy and labour market. Since – other things being equal – labour is expensive, troublesome and (in agriculture) relatively unproductive, whereas machinery is cheap, relatively reliable and highly productive, then increased labour productivity seems an obvious agricultural goal. The logic of the market is such that labour freed from agriculture can be redeployed more efficiently elsewhere.

But three points can be raised here to complicate the picture. First, other things are not equal – agricultural mechanisation comes at the cost of major environment externalities, only some of which are picked up in our remaining indicators, so there is a trade-off between labour productivity and sustainability.

Second, the redeployment of freed labour only occurs smoothly in situations of economic equilibrium and growth. Perhaps the short-term pain of the redundant worker needn't concern us too much if we assume that the economy will pick up soon enough and slot them back into the workplace. But if the redundancy is systemic and structural, then there may be grounds for advocating a less labour efficient agriculture. And the redundancy *is* systemic and structural, not only in the old Marxist sense of the capitalist need for a reserve army of labour, but also in the ecological sense that economic growth and its dynamic of labour productivity inevitably seems to involve the increasing, unsustainable drawdown of non-renewable natural resources, as Tim Jackson has shown in his recent survey of the prospects for a zero-growth economy. Jackson argues that, 'A key requirement is to reframe our preconceptions about both labour and capital productivities....Rather than stimulating a continued search for high productivities, it would be better to engage in structural transition towards low-carbon, labour-intensive activities and sectors'[10]. Low-carbon, labour-intensive agro-ecological smallholding might prove, then, to be one of the sunrise industries of the future low growth society.

Third, the labour economics that infuses the analysis of productivity and economic growth assumes wage labour as its basic unit. But farmers, and most particularly smallholders, are not wage labourers. Smallholders are often the last remnants of a petty proprietor class which has turned to wage labour through expropriation and not through choice in many countries over the past two hundred years (a process that continues to this day) – and we know that the economic behaviour and priorities of proprietors can differ radically from that of wage labourers and capitalists[11].

[10] Jackson (2009): 176.
[11] See eg. Chayanov (1986); Lasch (1991).

Doubtless this all seems a long way from the realities of today's agriculture. Although one can sometimes see within contemporary Toryism a shadow yeoman party yearning for a society of petty proprietorship – albeit probably not a very equitable one – modern politics is far too wedded to neoliberalism for politicians seriously to contemplate policies that might put 10 or 15% of the population into agriculture. But, as Jackson's analysis hints, this may well rise onto the political agenda sooner than a survey of the contemporary agricultural scene might lead one to think in view of the serious economic and environmental challenges we face. In this respect, the significant figure above is the 10-15% of the working population that would be needed to power a smallholder agriculture. If this figure had been anything approaching 100% then we could probably safely conclude that agro-ecological smallholding is not viable as a general model for UK agriculture (ILO figures indicate Ethiopia has the highest labour force participation in agriculture, at around 90%[12]). Figures of around 12-15% would put us on a par with countries such as Russia, Greece and Poland. I'm not suggesting that all farmland should be given over to agro-ecological smallholding. But notwithstanding the apparently poor labour productivity of the agro-ecological approach, it probably could be – and in the future this might even come to seem the wisest option.

Productivity per unit GHG emitted. Table 5 shows the greenhouse gas emissions (carbon equivalent) and sequestrations per hectare for the two farm systems, broken down by emission category.

Table 5: GHG Emission Sources

	Industrial farm ($kgC_{eq}ha^{-1}$)	Agro-ecological farm ($kgC_{eq}ha^{-1}$)
On farm fuel use	61	18
Off farm fuel use to point of consumption	103	50
Agro-chemical synthesis	85	0
Methane from livestock	94	139
Nitrous oxide	182	35
Tree sequestration	0	-186
Soil carbon additions	0	-3
Total	526	53

The agro-ecological smallholding has much lower on-farm energy related emissions because it undertakes only a little cultivation using light machinery. Delivery of produce off farm is also lighter in energy, largely because of the inefficiency of private motor transport in supermarket shopping. Per hectare methane emissions are higher because of the greater amount of permanent pasture, though these are offset by tree sequestration (there's room for some diversification away from ruminants on the agro-ecological holding, though I'm not persuaded that it's feasible to do away with them altogether despite their heavy GHG cost).

In Table 6, these values are then plugged into our productivity values from Table 1.

[12] ILO (2010)

Table 6: Food productivity per GHG emissions

	Food produced per GHG emissions ($kgkgC_{eq}^{-1}$)	Food energy produced per GHG emissions ($MJkgC_{eq}^{-1}$)	Protein produced per GHG emissions ($kgkgC_{eq}^{-1}$)
Industrial farm	11	130	1.04
Agro-ecological farm	183	370	2.86
Ratio	0.06	0.35	0.36

The table shows that the superior productivity of the macronutrients on the industrial farm fails to compensate for its heavier carbon footprint – the agro-ecological smallholding produces nearly three times as much energy and protein per unit GHG emission, putting the industrial farm in the shade on this significant public good.

Productivity per unit energy use: Table 7 shows energy usage on the two holdings.

Table 7: Energy usage

	Industrial ($MJha^{-1}$)	Agro-ecological ($MJha^{-1}$)
1 On farm fuel use	2,200	500
2 Embodied energy in machines	800	300
3 Agro-chemical production	7,300	0
4 Retail transport	4,800	3000
Total on farm (1-4)	10,400	900
Total (1-5)	15,200	3,400

My figure for on-farm use on the industrial holding of 10,400 $MJha^{-1}$ is only around half the figure reported by Cormack (2000), which may be a more accurate result. Likewise, the full energy costs of the industrial supermarket retail model have been considerably underestimated here (see Appendix), but I will stick with my policy of generosity towards industrial farming and proceed to examine productivity per unit energy use in Table 8.

Table 8: Food productivity per energy use

	Food produced per MJ energy used ($kgMJ^{-1}$)	Energy produced per energy used ($MJMJ^{-1}$)	Protein produced per energy used (gMJ^{-1})
Industrial on-farm	0.5	6.5	52
Agroecological on-farm	11	22.6	175
Ratio on-farm	0.05	0.29	0.30
Industrial total	0.4	4.5	36
Agroecological total	11.2	22.9	45
Ratio total	0.13	0.76	0.79

The table separates out on-farm and total energy productivities (the difference being the additional fuel cost of getting the produce to the customer). Even with the generous assumptions mentioned above, on-farm energy productivity on the industrial farm barely reaches 30% of the agro-ecological holding, and remains lower even when off-farm transport costs are considered. In a sense, Table 8 is the inverse of Table 4, reflecting the fact that the labour productivity of industrial farming is achieved by substituting fossil fuels for human labour (and at the same time reducing the agronomic complexity of the farming system in favour of a few macronutrient rich commodity crops), though it isn't quite a mirror image because of the relatively greater productivity of fuel over human labour. How best to choose between these two different forms of productivity as a matter of agrarian policy depends a lot on one's assumptions about the future energy supply, the impact of climate change and the nature of the labour market – themes to which I shall return briefly in the conclusion.

Biodiversity: There's no doubt that the agro-ecological smallholding is the more biodiverse of the two holdings. It grows a far greater variety of crops, and the genetic diversity within those crops is likely to be greater than that within the highly-manipulated genomes of the few industrial crop varieties. It also has a greater variety of habitats (permanent grass, temporary grass, trees, cultivated soil), and its regimens of tillage and pest control within those habitats permit a much wider biota to coexist within the farm ecosystem – this much is clear from ecological research[13].

Perhaps there is some uncertainty as to whether biodiversity is better served by small patches of different habitat on mixed smallholdings, or larger agglomerations of intense cultivation and wildland that may be permitted by the industrial model. However, as the analysis above demonstrates, it's probably not necessary to put any more land into cultivation even with a substantial change towards agro-ecological smallholding in order to feed the population, and land farmed agro-ecologically would certainly be more biodiverse. Moreover, although proponents of industrial agriculture are fond of pointing out that chemical-intensive cultivation can leave more land available for wilderness, it also has to be asked whether this would actually happen. Pressure on land for alternative uses in Britain is severe. Besides, I'd question whether a society that freely chooses an instrumental, agro-chemical agriculture over agro-ecological farming has the cultural willpower to choose wilderness over more managed landscapes.

Does biodiversity matter? The answer may depend on one's criteria for judgement, but it seems likely that even framing it in the most narrowly instrumental or anthropocentric terms, it's still the case that the farm system benefits from preserving biodiversity. Ecological studies suggest that greater ecosystem diversity is associated with greater stability, resilience and net productivity[14]. It's probable that the same applies to agro-ecosystems. Also, there is much that we don't know about the interactions between soil and terrestrial biota and human crops. It would seem prudent not to compromise them whenever possible.

Conclusion: Which Efficiency?

In summary, industrial agriculture produces more macronutrients (though not more food) per unit area and per unit labour, whereas agro-ecological smallholding produces more food and more macronutrients per unit GHG emissions and per unit energy used (and also probably per unit biodiversity, if such a thing could be determined). So the question is not which type of farming is more efficient. They're both efficient in their own ways. The question is which type of efficiency do we wish to emphasise?

Much depends on one's judgments about the future, both in relation to future resource constraints and to future socio-economic trends. Climate change further complicates the issue with its unpredictable future consequences.

The advocate of industrial farming can point to its considerable capacity to absorb growing food demands (leaving aside any awkward issues about food quality and social equity) and its realistic labour profile. Its dependence on non-renewable energy sources and its heavy carbon footprint are problems, but perhaps not insurmountable ones given possible technical innovation in the future. Its

[13] See, for example, Organic Research Centre (2010); Baldock et al (2011)
[14] eg. Yachi and Loreau (1999).

economic model is the global consumer and wage labourer, the familiar *homo oeconomicus* seeking to minimise work and maximise income and pleasure, who needs basic agricultural commodities to be provided as cheaply as possible by as small a labour force as possible.

The advocate of agro-ecological farming can point to its ability to grow enough food with minimal fuel use and GHG emissions. But they would have to concede that if this type of farming were to proliferate it would forge a very different economic landscape, and indeed a very different physical landscape. It would almost certainly have to involve a significant degree of deurbanisation and relocalisation. Its economic model is the petty proprietor, whose fundamental ethos involves a duty of care to their property, an approbation of personal and community self-reliance, and a belief in honest return for honest work.

The detached global consumer and the embedded local proprietor are related stereotypes who are yoked together in modern political discourse (witness the contradictory sloganeering of politicians on 'consumer demands' and 'hard-working families'). If the agro-ecologist's world of locally embedded smallholders seems more utopian than the industrial farmer's world of detached consumers, perhaps it's because of the now largely forgotten defeat of agrarian populism as a political movement throughout much of the world during the nineteenth and twentieth centuries. But though neoliberalism has taken us a long way towards *homo oeconomicus*, its utopian ideal of the purely selfish utility-maximiser seems destined to ultimate failure in the face of the continued assertion of local affect and conservation. There seems to be no clear winner in the contrasting social utopias of industrial and agro-ecological farming.

That just leaves the techno-utopia of industrial farming – its implicit belief that its tremendous fossil energy usage and carbon footprint can be remedied by future technological innovation. That may prove to be correct, but it's a risky punt. One might think that a prudent policymaker surveying the scene with the currently available information would hedge their bets by adopting a mixed strategy of energy-intensive and agro-ecological farming. Since current policies overwhelmingly incentivise the former, such a strategy would involve taking radical steps to encourage agro-ecological smallholding. But let's not hold our breath.

Appendix: Constructing The Indicators

1. Productivity

Industrial wheat: 7810 kgha^{-1}, 14 MJkg^{-1}, 0.106 kgkg^{-1} protein
Industrial barley: 5760 kgha^{-1}, 14.4 MJkg^{-1}, 0.105 kgkg^{-1} protein
Industrial potatoes: 41,500kgha^{-1}, 3.72 MJkg^{-1}, 0.02 kgkg^{-1} protein
Industrial oilseed rape: 3120 kgha^{-1}, 15.5 MJkg^{-1}, 0.23 kgkg^{-1} protein
Industrial beef: 146kgha^{-1} (estimated), 11.7 MJkg^{-1}, 0.16 kgkg^{-1} protein

Sources: DEFRA (2011), Paul & Southgate (1978), USDA (2011)

Agro-ecological wheat: 2631 kgha^{-1} (estimated)
Agro-ecological potatoes: 26,975 kgha^{-1}
Agro-ecological vegetables (overall average): 35,700 kgha^{-1}, 1.2 MJkg^{-1}, 0.045 kgkg^{-1} protein
Agro-ecological lamb: 102kgha^{-1}(estimated), 13.8 MJkg^{-1}, 0.15 kgkg^{-1} protein
Agro-ecological nuts: 714kgha^{-1} (estimated), 13.8 MJkg^{-1}, 0.15 kgkg^{-1} protein
Agro-ecological fruit: 4690kgha^{-1} (estimated), 1.4 MJkg^{-1}, 0.0029 kgkg^{-1} protein
Agro-ecological honey: 30kg, 12720 MJkg^{-1}, 0.003 kgkg^{-1} protein
Agro-ecological shiitake mushrooms: 75kg, 2310 MJkg^{-1}, 0.031 kgkg^{-1} protein

Sources: Vallis Veg Records, Paul & Southgate (1978), USDA (2011), Crawford (2010), Logsdon (2009)

2. Energy & GHG Emissions

Industrial on-farm energy use: 10,400 MJha^{-1}
C emissions: 49.6 kgC$_{eq}$ MJ^{-1}
Industrial off-farm fuel use: 600 MJt^{-1} to packer, 32 MJt^{-1} to supermarket (100km in 25t lorryload @ 22l fuel/100km), 273 MJt^{-1} shoppers' trips (20kg per 3km trip @ 5l fuel/100km), emissions 0.732 kgCl^{-1}
Agro-ecological on-farm energy use: 874 MJha^{-1}
Agro-ecological off-farm fuel use: 257 MJt^{-1} van delivery (2.75 customers/km @ 8.8 km/l)
Methane from livestock: 54.9 kg/beef cow@ 1.3ha^{-1}; 7kg/sheep @ 4 ewes ha^{-1}.
Methane @ 5.74 C equivalence
Nitrous oxide: 1.25% per unit N added @ 84.7 C equivalence. N applied 169kgha^{-1} industrial, 57kgha^{-1} agro-ecological.
Tree sequestration: 280kgCha^{-1}
Soil carbon sequestration: 20kgCt^{-1} added manure

Sources: Vallis Veg Records, Audsley et al (2009), Cormack (2000), DEFRA (2000; 2003; 2010a; 2010b), DFT (2009), Smaje (2010a), IPCC (2011)

References

Audsley, E. et al (2009). *Estimation of the Greenhouse Gas Emissions from Agricultural Pesticide Manufacture and Use*. Cranfield University.

Baldock, D. et al (2011). *Public Goods and Public Intervention in Agriculture*. IEEP.

Brand, S. (2010). *Whole Earth Discipline*. Penguin.

Chayanov, A. (1986). *The Theory of Peasant Economy*. Wisconsin.

Cormack (2000). *Energy Use In Organic Farming Systems*. MAFF Project OF0182

Crawford, M. (2010). *Creating A Forest Garden.* Green Books.

DEFRA (2000). *Fertiliser Recommendations*.

DEFRA (2003). *Development of economically & environmentally sustainable methods of C sequestration in agricultural soils.*

DEFRA (2007). *The effects of reduced tillage practices and organic material additions on the carbon content of arable soils.*

DEFRA (2010a). *National Food Survey*.

DEFRA (2010b). *Observatory Programme Indicators C: Farm Management*.

DEFRA (2011). *Agriculture in the United Kingdom*.
http://www.defra.gov.uk/evidence/statistics/foodfarm/general/auk/index.htm

DFT (2009). *National Travel Survey*.

Duncan, P. (1996). 'The Olduvai theory: sliding towards a post-industrial Stone Age'
http://www.dieoff.org/page125.htm

ILO (2010). *Key Indicators of the Labour Market.* http://www.ilo.org/empelm/what/lang--en/WCMS_114240/

IPCC (2011). *Emissions Scenarios.* http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=78

Jackson, T. (2009). *Prosperity Without Growth*. Earthscan.

Lasch, C. (1991). *The True And Only Heaven*. Norton.

Logsdon, G. (2009). *Small-Scale Grain Raising*. Chelsea Green.

Organic Research Centre (2010). *The Biodiversity Benefits of Organic Farming.* ORC.

Paul, A. & Southgate, D. (1978). *The Composition of Foods*. HMSO.

Perfecto, I. and Vandermeer, J. (2010). The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 13: 5786-5791.

Smaje, C. (2010a). 'Land use options for sustainable farming' *Agroforestry News*, 18, 3: 10-17.

Smaje, C. (2010b). 'Small farm permaculture' *Permaculture Magazine*. 65: 47-50.

Smaje, C. (2011). 'Towards a market garden economy'. Unpub MS.

Smil, V. (2001). *Enriching the Earth*. MIT Press.

Smil, V. (2010). *Energy Myths and Realities*. AEI Press.

UK Greenhouse Gas Inventory (2011) http://www.ghgi.org.uk/sector.html

USDA National Nutrient Database http://www.nal.usda.gov/fnic/foodcomp/search/

Yachi, S. and Loreau, M. (1999). 'Biodiversity and ecosystem productivity in a fluctuating environment' *Proceedings of the National Academy of Sciences of the United States of America*, 96, 4: 1463-1468.