LAND USE OPTIONS FOR SUSTAINABLE FARMING

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Introduction

Modern farming faces the threefold challenge of producing enough food to feed humanity while trimming its use of dwindling fossil fuel reserves and avoiding contributing to climate change. Of the various possible ways of tackling these problems, one that is widely touted (albeit rarely within rich countries) is diverse, small-scale, labour-intensive, fuel-lean farming. As a small-scale farmer myself (running a local veg box scheme from 7 hectares in Somerset), this article arose from an attempt to answer for myself what mix of land uses I should adopt in order to help address these agricultural challenges. Inasmuch as some of my answers can be generalised, it seemed to me that they might be of interest to other small-scale farmers, and perhaps to the wider policy community.

Four criteria for sustainable agriculture

As a starting point, I propose four 'technical' criteria for sustainable agriculture (as opposed to social/economic criteria, which I don't consider here). Thus, the sustainable farm should aim to:

(1) Maximise food productivity (per unit area and per unit labour), because it's better to produce the food we need with less rather than more land so that other land can be put to other uses (or left alone). Likewise, the less labour that's needed for farming, the more it's possible for people to do other (useful and/or important) things.

(2) Minimise greenhouse gas emissions, because farming is a significant source of these emissions through the burning of fossil fuel, the oxidation of soil carbon during cultivation, the keeping of methane-producing livestock, and the production of nitrous oxide through soil fertilisation and animal husbandry, when it could be a net carbon sink through careful soil, plant and stock management.

(3) Minimise fossil fuel use, not only because of its contribution to climate change but also, being non-renewable, because we can't rely upon its long-term availability.

(4) Maximise cultivated and wild biodiversity, because ecological health is generally improved when we avoid monocultures, and the greater the genetic diversity of the agricultural landscape the more resources are available for countering the threats posed by pests, diseases and climatic change.

In practice, there are trade-offs between these four goals. Modern arable farming, for example, maximises labour productivity – perhaps even to a degree that is socially undesirable – but certainly doesn't minimise fossil fuel use or carbon emissions. There are also hidden trade-offs within specific goals. For example, a stock-free organic agriculture based upon green manure leys may decrease the carbon emissions associated with livestock, but increase the emissions associated with tillage and fuel use.

Assessing land use options

To steer a course through these difficulties, I've attempted to assess different forms of land use against three main quantitative indicators:

Food energy produced (Megajoules per hectare per year), which addresses criterion (1) above. The calorific content of our food is not the only worthwhile productivity measure, but it does address the 'bottom-line' function of keeping us alive and makes for an easy comparative baseline. I should point out, though, that the figures I present below for organic vegetable production refer to the cultivation of around 30 different kinds of vegetables for a box scheme, many of which are low in calorific content – the analysis is not primarily concerned with maximising energy returns above all else (if it were, I'd just grow potatoes). Also, the energy productivity of different land use options can look very different depending upon whether gross or net energy is considered – here I mostly look at gross energy, because net energy is implicitly considered in the third indicator.

Carbon emissions produced (Tonnes of CO_2 equivalent per hectare per year), which addresses criterion (2) above. This figure is based on emissions from soil cultivation, fossil fuel use and livestock methane emissions. I haven't considered nitrous oxide emissions, because there doesn't appear to be a consensus in the literature over the effect of various fundamental agricultural decisions (tillage or no tillage, organic or non-organic) on emission levels. This means that my calculations understate the true level of agricultural emissions – probably by a considerable margin, since nitrous oxide emissions account for around half of all agricultural emissions. But while it remains unclear what, if any, strategies can be taken to reduce these emissions, it seems best to exclude them from consideration here. My calculations also possibly overstate sequestration gains if read as a long-term analysis, since the carbon accumulation capacities of soils and other agricultural sinks can level off after time. However, this scarcely justifies options with poorer short-term sequestration gains.

Fossil fuel used (Litres of diesel per hectare), which addresses criterion (3) above. The figure is based principally on tractor/vehicle use.

Assessing biodiversity is more complex and less easily quantified – I restrict myself to a few general comments below where appropriate.

The indicators are based on on-farm production, not processing beyond the farm-gate, and focus on recurrent annual activity rather than embodied or capital items such as farm buildings or vehicles.

The land use options considered are as follows:

1. *Conventional vegetables, 'chemical' tillage*: involving annual tillage and the application of manufactured fertilisers and pesticides.

2. *Organic vegetables, stock-free no till (offsite fertility)*: involving zero tillage organic growing, with the fertility bought in from off site in the form of municipal green waste compost.

3. *Organic vegetables, stock-free no till (onsite fertility)*: involving zero tillage organic growing, with the fertility grown onsite in the form of a permanent green manure sward which is cut mechanically and composted for application to the vegetable crops.

4. *Organic vegetables, stock and tillage (onsite fertility):* involving organic growing, with the fertility grown onsite in the form of temporary green manure leys which are grazed and then tilled in for vegetable production.

5. *Pasture:* low input/low output permanent pasturage for grass-fed sheep or beef cattle (a fertility-producing system which can be combined with Option 4).

6. *Nut orchard:* chestnuts, walnuts and hazelnuts, with the grass in between cut mechanically.

7. *Nut agroforestry:* nut orchard with ruminants grazing between the trees.

8. *Woodland:* natural woodland lightly stocked with pigs (which can also be combined with Option 4, using the pigs for fertilising and ploughing in the vegetable rotation).

<u>The Results</u>

In order to compute figures for the chosen variables it's necessary to make a whole host of (potentially questionable) assumptions, which would hopelessly encumber the text if they were all spelled out here. Below I mention a few of my key assumptions – the full underlying data and references are available at: http://www.vallisveg.co.uk/landuseoptions.html. I make no claim to have produced a definitive or comprehensive analysis – rather, the research is intended as a first approximation which can hopefully be refined in the future.

<u>Energy Productivity</u>

Table 1 shows the energy productivity of the different options. The figures for the organic vegetable production options are based on the actual productivity measured on my holding over the last growing season, whereas the other figures are based on average productivity figures from the literature. Gross energy productivity refers to the total food energy produced by the option in question, while net energy productivity refers to total food energy produced less fossil fuel energy used in production.

Table 1: Annual Energy productivity (MJ/ha)

	Gross	Net
Conventional Veg	38,200	30,500
Organic Veg (no till, offsite)	34,300	15,100
Agro-forestry (nut + stock)	31,000	30,100
Nut Orchard	29,000	28,000
Organic Veg (stock + tillage)	28,500	27,200
Organic Veg (no till, onsite)	17,100	15,600
Pasture	2,000	2,000
Woodland	700	700

Despite the common claim that organic methods are less productive per unit area than conventional methods, the first two figures in the left-hand column show that this is only barely the case (in fact I've computed various different models, some of which suggest that my system is *more* productive than the conventional one – the model used here, though, is amongst the more cautious. However, I suspect that it is eminently possible for small-scale organic growers to achieve equal or better returns per unit area than conventional growers, and indeed this finding is not uncommon in research on small-scale growing).

The organic options requiring fertility to be produced onsite *are* less productive because part of the cultivable space has to be devoted to non-food fertility-building crops (this cost is exported offsite in the case of chemical fertiliser or bought-in compost, but manifests itself in the higher energy costs that are shown in the right-hand column; see also Table 3). Even so, the stock + tillage option still performs reasonably well, at around 75% of conventional gross productivity (and 89% of net productivity – remembering, of course, that this is a conservative estimate of organic productivity). This is considerably better than the onsite zero tillage option, largely because it uses the fertility of the green manure crop more efficiently. The nut orchard and agro-forestry options perform well, although at present these are quite experimental so the figures should be treated cautiously (high-yielding nut crops remain quite marginal in the west country climate). Stock on permanent pasture produce much less food energy per unit area (an 'efficiency' argument against livestock commonly used by advocates of veganism), though there are economic and ecological arguments in their favour. The woodland option is even less energetically productive in terms of food energy, though of course the timber it can produce is another valuable product both energetically and for other uses.

<u>Carbon emissions</u>

Table 2 shows the net greenhouse gas emissions associated with the options. These figures are based upon carbon dioxide emitted through the onsite combustion of fossil fuels and through ploughing and/or tillage (assuming emissions of 715kg of CO_2 per hectare annually through tillage). They also include methane emissions from ruminant livestock (expressed in terms of carbon dioxide equivalence). 'Upstream emissions' associated with the importation of fertility are included for the conventional veg and organic no till offsite options – the latter figure is based upon my particular situation, which would require me to import compost from a landfill site about 25km from my holding (here, I've disregarded the countervailing carbon-saving potential of green waste when it's composted rather than sent to landfill. This is arguably a harsh assumption – it's based upon the view that in an energy-scarce future the choice will not be between transporting green waste to landfill and transporting it to compost, but will have to involve using it at or near the point of genesis).

The sequestration of carbon in undisturbed soils and plant biomass (trees, permanent pasture, green manure leys) is also considered; pasturage figures include 10% woody forage. Where sequestration outweighs emission, the resulting net figure is negative.

Table 2: Annual net carbon dioxide emissions (t/ha)

Woodland	-12.9
Nut orchard	-5.7
Agro-forestry (nut + stock)	-3.7
Pasture	-2.4
Organic Veg (no till, onsite)	-0.6
Organic Veg (stock + tillage)	-0.3
Organic Veg (no till, offsite)	0.6
Conventional Veg	1.3

The options involving the undisturbed growth of trees, pasture or green manure leys do the best here and, as the table shows, act as potentially significant carbon sinks. The negative pasture figure suggests that the methane emissions of ruminants are more than offset by the sequestration of carbon in permanent pasture and woody forage. It should be noted that this figure applies *only* to ruminants fed a pure forage diet without concentrates; even so, it suggests the common view that ruminants are inevitably an evil when it comes to greenhouse gas emissions is not necessarily the whole story when livestock are considered in the context of the larger ecological system of which they form a part.

The onsite vegetable options are also carbon-negative, because they involve either no tillage or tillage limited to only part of the rotation, which is more than offset by sequestration accrued in other parts of the rotation. The two worst options are the ones that were the most productive in Table 1 – exporting the responsibility to produce fertility offsite comes at the expense of heavy fossil fuel costs, with associated emissions. The tillage associated with conventional growing further adds to its emission burden.

<u>Fuel use</u>

Table 3 shows the fossil fuel use associated with the different options – principally diesel used onsite, but including the costs of manufacture or transport for fertility generated offsite where relevant. This is effectively a measure for the resilience of the different options to peak oil and/or energy scarcity.

Table 3: Annual fuel use (l/ha)

Woodland	0
Agro-forestry (nuts + stock)	0
Pasture	0
Nut orchard	25
Organic Veg (stock + tillage)	37
Organic Veg (no till, onsite)	41
Conventional Veg	213
Organic Veg (no till, offsite)	525

Again, the onsite fertility options indicate a far lesser use of fossil fuels (though to some extent they rely upon the substitution of human for mechanical work). The pasture option assumes no mechanical hay or silage-making, which seems reasonable for meat animals at low stocking densities on permanent pasture in a foggage/ extended grazing system – provision for some mechanical haymaking wouldn't change the overall picture much. The organic offsite option comes off particularly badly because of the fossil fuel costs associated with collecting and transporting bulky composts and feedstocks over significant distances.

Some Conclusions

To begin putting these results together into a more useful overall picture, Tables 4 and 5 provide composite figures of the preceding data in the form of food energy per carbon emissions and food energy per fuel used respectively. It should be noted that in Table 4 there are two methods for calculating the relevant values. In the options involving net carbon sequestration food energy is multiplied by carbon sequestration to give an *energy x sequestration* figure since our aim is to maximise both quantities. In the options involving net carbon emission food energy is divided by carbon emission to give an *energy / emission* figure since our aim is to maximise the former and minimise the latter. The interpretation is that the larger the negative number is the better in the sequestration options, and the larger the positive number is the better in the emitting options, but the positive and negative figures can't be compared directly because they're not on the same scale.

Table 4: Food energy in relation to carbon emissions

Nut orchard	-165,000	MJ.t
Agro-forestry (nuts + stock)	-115,000	MJ.t
Organic Veg (no till, onsite)	-10,000	MJ.t
Woodland	-9,000	MJ.t
Organic Veg (stock + tillage)	-8,000	MJ.t
Pasture	-5,000	MJ.t
Organic Veg (no till, offsite)	54,000	MJ/t
Conventional Veg	29,000	MJ/t

Table 5: Food energy in relation to fuel use (MJ/l)

Agro-forestry (nuts + stock)	∞
Pasture	∞
Woodland	∞
Nut orchard	1,160
Organic Veg (stock + tillage)	780
Organic Veg (no till, onsite)	420
Conventional Veg	180
Organic Veg (no till, offsite)	70

Of the various options, the ones that produce reasonable food returns while still sequestering carbon by minimising tillage and fuel use obviously come out best. On the face of it, the rather experimental options of a nut orchard or nut orchard plus ruminant pasture are favoured. The traditional organic system of grazed leys rotating with arable/vegetable crops (stock + tillage) also performs well in relation to fuel usage. Although this option requires tillage it can be kept to a minimum with good rotation planning, and fossil energy requirements can further be reduced by the use of pigs to root up the ley. The onsite (stockfree) zero tillage option of cutting and composting green manure slightly outperforms the stock + tillage option in terms of emissions, but is less fuel-efficient. Again, the offsite fertility options of imported synthetic or green waste fertiliser do not perform so well in terms of either carbon emissions or fuel use.

Rather than adopting single forms of land use as may have been implied in the preceding analysis, real world farming situations demand a mixture of uses. The analysis here is useful, though, in highlighting the kind of options that could be combined to create a productive, resilient and non-polluting farm. On my own holding, I'm in the process of establishing a system comprising the following elements:

- woodland as a carbon sink, source of non-food products, reservoir for wild biodiversity, source of compost and 'home range' for pigs, the latter also providing fertility, pest control and cultivation elsewhere in the system as well as a modest supply of meat
- nut orchard as an 'enhanced' or more food-productive form of woodland
- pasture and wood pasture as a carbon sink and home range for ruminants, the latter also providing fertility elsewhere in the system and a modest supply of meat
- organic vegetable production, with fertility generated onsite through green manure leys and through pigs, cattle and poultry (which also provide pest control and cultivation)

On the basis of the preceding analysis, I estimate that the system I'm creating will produce at least 21,000 MJ of food energy per hectare annually (of which around 5% would be from meat or eggs), while sequestering more than four tonnes of carbon dioxide per hectare and using as little as 18 litres of diesel per hectare (which is only around 8% of fuel usage associated with conventional cultivation). If this were to be scaled up over the 12 million hectares of existing UK farmland (with a lesser figure applied to the 5 million hectares of rough grazing and woodland) it would provide more than enough food to feed the current UK population, albeit on a diet to which it is not presently accustomed and without taking account of the kind of geographical/ distributional issues facing us in a fossil-energy constrained future that could make food scarcity a real possibility in certain areas. But these figures at least provide some grounds for doubting two common objections to small-scale, low-impact organic growing – namely that it will not be productive enough to feed the country, and that it will require us to expand the margins of agricultural cultivation. In this sense, my findings complement those of Simon Fairlie in his article 'Can Britain feed itself?' (*The Land*, No.4 2007-8, pp.18-26).

The system I'm proposing could easily be intensified to produce an even higher productivity per unit area. However, doing so would inevitably involve intensifying the fertility-making part of the system, probably by growing more green manures at the expense of woodland, grassland and livestock. This would reduce the biodiversity of the system in terms of both wild and cultivated plant and animal species, and probably compromise its overall resilience. The benefit of the productivity gain would have to be judged carefully against this loss.

Since small-scale, low-impact organic agriculture is more labour intensive than modern conventional farming, a remaining question is how big the agricultural workforce would need to be if the kind of farming I've been suggesting here were generalised across the UK. Assuming the need for three full-time workers on a 7 hectare farm of the kind I operate (and one full-time worker per 25 hectares of rough grazing or woodland), this equates to a need for around 15% of the current UK working-age population to be employed directly as farmers. Given the enormity of the challenges we face in relation to climate change and peak oil, this figure seems to me encouragingly achievable, although it's probably too high to command serious attention from current policy-makers (its implications could be sweetened a little in various ways, such as through substituting volunteer labour or instituting national community service in agriculture). Still, in a world lurching between ever-escalating fiscal and environmental crises in which the long-term sustainability of jobs in other sectors can no longer be assumed, the high labour demands of small-scale organic farming may turn out to be one of its more attractive features for enlightened policy-makers in the longer run. This method of farming may in any case be the least worst option if we are to weather the impending shocks of climate change and energy scarcity, whether we like its labour implications or not.

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