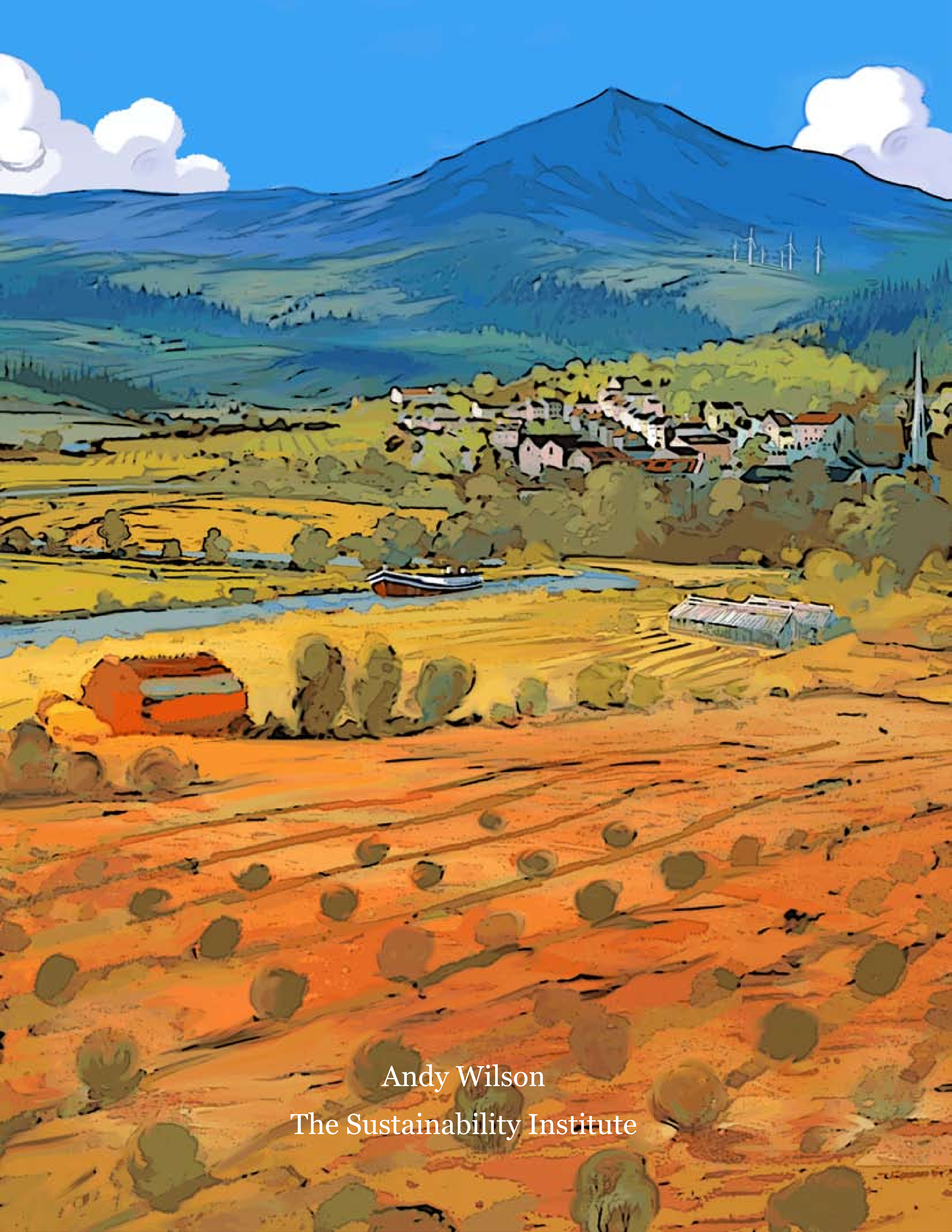
Options for Tillage in Post-Oil Ireland



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Options for Tillage in Post-Oil Ireland

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Options for Tillage in Post-Oil Ireland - Introduction

Earlier work has identified the tillage resource as approximately 900,000-950,000 hectares (ha). This is slightly less than the maximum tillage achieved during WW2. The area identified refers to agricultural land and does not include gardens or allotments. It should be noted that the existence of the resource is no guarantee that it will all be utilised, or that it will be managed well. Various socio-economic and political factors may delay, limit or otherwise hinder the development of the tillage resource.

The limited availability of fuel for tractors, and other energy-related factors, will impose many constraints upon tillage capability in post-oil Ireland. Currently, agriculture is 100 percent dependent on imported oil for tractor fuel. The manufacture of both agricultural equipment and the machinery needed for the production assembly lines is heavily predicated on fossil fuel availability, as is the extraction and processing of raw materials used in production.

Although maintaining agricultural production at levels capable of feeding the entire population will be of paramount importance, vehicle fuels will also be needed for food distribution, the transportation of other essential goods, and a variety of other tasks, including the transportation of people. A well organised and equitable post-oil society, should it exist, will attempt to allocate the available fuel to end uses that deliver the greatest societal benefits.

This article will examine the options for conventional tractor-based tillage, and briefly investigate the alternatives using animal power and human labour. This will provide an overview of the land tillage capability in post-oil Ireland, and highlight possible ways by which the outcome can be improved.

Conventional Production

There are currently about 60,000 licensed tractors in use in Ireland, and an unknown number of unlicensed vehicles. Roughly this works out at one tractor for every two of Ireland's 120,000 agricultural holdings. However, tractor ownership is heavily weighted towards the tillage sector, currently comprising some 10,000 holdings.

There is likely to be a high utilisation of tractors on holdings where there is significant tillage. On other holdings, tractor use may be more occasional, and largely confined to the spreading of slurry and transportation of materials. Some tractor use may be solely for personal transportation within or outside the farm. Overall, the Irish tractor resource is probably underutilised.

The numbers of tractors in use in Ireland can be expected to fall in the next few years. The reasons for this include the general trend towards reduced amounts of tillage, the preference among non-tillage farmers for four wheel drive SUVs and quad bikes over tractors for transporting feedstuffs and other agricultural materials, the falling number of holdings as farms are amalgamated, and also economic factors that oblige farmers to limit capital expenditure.

Although further work is needed to confirm this, it appears likely that a future tractor fleet with the equivalent combined horsepower of the tractors currently used in Ireland would be adequate for the purpose of working up to 1,000,000 ha of tillage. This presumes that deployment of tractors and associated equipment would be carried out in an optimal way, which may or may not be the case. An even more pertinent question concerns the availability of fuel as without fuel the tractor fleet is only scrap metal. A related issue is the maintenance and the supply of spare parts. However, the experience of Cuba demonstrates that human ingenuity can overcome lack of spare parts, while maintenance skills can be learned.

According to recent data from SEI, agriculture is responsible for 2.3 percent of final energy consumption in Ireland - about 300 KTOE (thousand tonnes of oil equivalent). Diesel fuel comprises 80 percent of this: 250 KTOE or about 290 million litres. The exact portion of this used for tillage is unknown, but is estimated to be in the region of 50 million litres. This figure is extrapolated from a UK study - the Levington Agricultural Report - that found 120-130 litres of diesel were required for every one hectare of tillage. The corresponding figure for silage is estimated to be 70-75 litres per ha. There are about 1 million ha of silage in Ireland. This suggests that a further 70-75 million litres of fuel is used annually in producing silage.

Area of tillage

At present, Ireland has about 400,000 ha of tillage. The future area available for tillage has already been estimated at 900,000-950,000 hectares (ha). However, not all this land would be tilled in any one year, as some land would be left fallow. The average annual tillage can be assumed to be 675,000-750,000 ha. However, there will be considerable variation in the level of activity required between different parcels of land, as this will depend on the type of crop, methods of cultivation, soil type, inclination (steepness), and other factors.

It seems unlikely that the increased tillage requirement can be met, using conventional machinery, without proportionately greater quantities of fuel being available. Therefore, the future fuel requirement for tillage may be as high as 85-95 million litres per annum. While future fuel requirements for silage production may be significantly lower than at present, owing to lower livestock numbers, the combination of silage and tillage fuel requirements will be similar to at present. A reasonable estimate is 110-120 million litres for silage and tillage combined. Given that imported oil will not be available in the future, agricultural fuel will have to be produced in Ireland from other sources.

Biodiesel

Oil-seed rape is currently used to produce a vegetable oil that can be used as a diesel substitute. Typical yields of vehicle grade fuel are 1100-1500 litres per hectare of crop. It should be noted that biodiesel has an energy density some 10-12 percent lower than conventional diesel, so more fuel is needed to get the same output. It would take 125-135 million litres of biodiesel to meet enviasged future tillage and silage fuel requirements.

The yields quoted above are contingent on generous applications of artificial fertiliser. The energy return on energy (eroei) invested on biodiesel from oil-seed rape is very low: under 2:1. The Levington report estimated the eroei at 1.78:1. A significant proportion of the total energy invested - roughly one quarter - is used in the production of artificial fertiliser and other agrochemicals. Agricultural and other transport fuels comprise about 18 percent of total energy inputs. This is the equivalent of 10 percent of the final energy yield in biodiesel.

The yield from oil seed rape grown without artificial fertiliser will be much lower: possibly around 500 litres per ha. It is likely that agricultural and other fuel inputs, when expressed as a proportion of energy output, will rise from 10 percent to 25-30 percent. This is because the energy required for tillage will remain largely unchanged, even though the crop yield will fall by up to two thirds.

To produce 120 million litres, the annual tillage requirement would be 240,000 ha. Assuming oil-seed rape is grown on a 4 year cycle, this would entail Ireland having at least 960,000 ha of available tillage. Given the tillage resource constraints, this is unlikely to be possible. Even the most optimistic allocation of land would provide only enough oil-seed rape to meet about 50 percent of estimated tillage and silage fuel requirements. Such an allocation would entail including the oil seed rape in a four year cycle with wheat, with a total land allocation of 500,000 ha (125,000 ha per individual crop). Such a regime would place considerable demands on soil fertility. Most likely, such a regime could not be sustained for long in the absense of artificial fertilisers.

More realistic would be the inclusion of oil seed rape solely in a longer five year cycle, with an extra fallow year added in order to maintain soil fertility. Given an annual land allocation of 100,000 ha and a yield of 500 litres per ha, this would provide an annual output of 50 million litres. This is the estimated gross output. From this agricultural and transport fuel requirements must be subtracted. This gives an agricultural net yield of 35-38 million litres, or about 26-30 percent of the envisaged tillage and silage fuel requirements. Other energy expenditures associated with production could be met using other fuels.

Even if silage was sacrificed and the entire oil-seed rape fuel output was given over to crop production, it would fall woefully short of meeting tillage fuel demands (95-100 million litres of biodiesel). And it would leave nothing at all other agricultural fuel requirements such as hay making or spreading slurry.

Just one final question remains, could yields achieved under sustainable agriculture be increased beyond the modest estimate of 500 litres per hectare? Could they be increased to 1200 litres per ha to rival the typical yields achievable under conventional agriculture? Using organic methods, this would appear a very big ask. However, if achieved it would bring in a gross harvest of 120 million litres of biodiesel per annum. From this one must subtract 12-15 million litres expended in growing the crop. This gives a net agricultural yield (this excludes energy used in processing, which might be derived from other sources) of 105-108 million litres - sufficient to run the tractors required for Ireland's tillage but with little left over for silage or other uses.

Fuel requirement in diesel and biodiesel

Tillage requirement per ha: 130 litres diesel

Future tillage requirement (of 950,000 ha) = 123 million litres conventional diesel

Energy per litre: Diesel 36.5 MJ/litre Biodiesel 32.6 MJ

Future tillage requirement in biodiesel = 139 million litres

Other Fuels

Given the near certainty that biodiesel from oilseed rape, on its own, will not provide sufficient fuel to meet the needs of Irish agriculture, other potential tractor fuels or energy sources must now be considered.

The principal alternatives are as follows:

Biogas
Ethanol
Electricity
Hydrogen

Biogas

Gas (usually methane) is used to power a wide range of vehicles, including heavy goods vehicles and buses. Biogas is the term given to gas produced from biological sources (material that was recently living). It normally involves the anaerobic digestion (AD) of plant or animal material, though can be produced using other methods too, wood gasification/pyrolysis for example. A wide variety of feedstocks can be used. These include municipal and abattoir wastes, human sewage, animal manure, and fresh plant material such as silage. From an agricultural perspective, the latter two categories are of most interest.

Globally, animal manure is widely used as a feedstock for AD. Within developed countries, AD is typically carried out on an industrial scale, with AD plants being located close to large industrial-size farm units. Such operations are highly dependent on intensive (fossil fuel-based) agriculture. There is a certain irony in this. Gas derived from AD is made up mainly of methane, and can easily be purified to a standard capable of being used in a combustion engine. In Sweden a train is powered by biogas.

More recently, interest has turned to running tractors from gas, particularly biogas produced on farm. The main difficulty lies in the fact tractors are designed to run off diesel. While theoretically possible, there is no easy process for modifying diesel engines to run solely from gas - in terms of resource use it may be just as efficient to replace the entire engine. This in turn will require considerable energy and capital investment.

A possible compromise may be use diesel biogas mixtures for fuel. This has already been demonstrated to work at a fuel ratio of 50:50 in unmodified diesel engines. If the fuel mix could be extended to include biodiesel/biogas mixes, then this would enable biofuel resources to be utilised to much better effect.

The energy value of refined gas (from mineral or biological sources) is approximately 5800 kWh (0.5 TOE) per 1000 m^3, or the equivalent of 580 litres of diesel.

In the developed world, AD is generally carried out at community or village scale. This model is the one most likely to reflect future circumstances in Ireland. Producing the gas on site eliminates the need to move bulky raw materials over distance, thus giving a better return on energy invested. In the case of animal manure, the energy investment is very low, as the raw material would already exist on any farm with housed livestock. However, beyond a certain point, extra animal numbers become counter productive owing to the difficulties of feeding the animals or due to the inherent inefficiencies in using good land for livestock farming.

Post-oil, the typical farm community using slurry for AD will have access to good pasture land unsuited to tillage, whilst also having tillage land elsewhere. The good pasture land will permit livestock farming, while the tillage land will provide the end use for the resultant digestate (the residue from the AD process). Estimates of AD yield from animal manure vary considerably. In the Mayo Energy Audit, a ballpark figure of 21 m^3 of gas per tonne of slurry was used. This works out at about 100 m^3 per cow per annum, the equivalent of 58 litres of diesel or sufficient to intensively till about 0.5 ha of land.

other fuels cont...

This figure excludes the energy used in the production of the biogas. Also, it should be noted that contemporary breeds of cows are very large. In the future, smaller breeds may be used. This is likely to result in lower yields of slurry per animal.

To sum up, the slurry from one contemporary cow would provide the energy to till half a hectare of land. Assuming full utilisation of slurry, it would require the output from 1,300,000-1,400,000 cows to provide sufficient fuel for tillage alone. This is probably close to the maximum number of cows Ireland could support in post-oil agriculture. More pertinently, the volume of slurry available will be proportionately far less than at present, as the sustainable methods of livestock farming employed in the future will involve less housing. Also, biogas produced on small farm units will most likely be used for heating rather than for agricultural fuel.

Given the large number of variables involved, it is hard to accurately assess the possible contribution of biogas from slurry towards agricultural fuel needs, but it is likely to be quite small.

Biogas from Silage

The Mayo Energy Audit identified biogas from silage as potentially the biggest of the AD/biogas resource, simply because of the sheer volume of material available. Ireland cuts some 1,000,000 ha of silage per annum, with a yield of tens of millions of tonnes. While silage has been shown to produce 120 m^3 of methane per tonne of raw material, the case for its utilisation as a suitable mass feedstock for AD has yet to be argued. However, one ha of land, even without the use of artificial fertilisers, will comfortably produce 15-20 tonnes of silage per annum while it will only support one cow. On this basis alone, it appears to have far better prospects for the mass production of biogas than slurry.

A twenty tonne per ha yield would produce 2400 m^3 of methane, equivalent in energy terms to almost 1400 litres of diesel - sufficient to till 10-12 ha of land. Another plus is that the energy return on fuel energy invested in producing biogas would be quite high, perhaps 5-8:1. In order to get the best returns, AD would have to be carried out at farm or local community level. This would minimise the transportation of very bulky raw input material, and also of the resultant digestate back to the land. Ideally the biogas would also be utilised locally. However, the filling of pressurised containers with gas (for export to other areas) would not be beyond the capabilities of local community-sized AD facilities.

The main difficulty with using biogas as an agricultural fuel, as mentioned above, is in its incompatibility with existing agricultural equipment. There is little likelihood of an easy procedure being developed to convert diesel engines to run off biogas as the respective combustion processes for the two fuels are fundamentally different. Conversion of existing equipment would involve replacing or rebuilding the entire engine. While this can be considered a more viable option than the replacement of the entire agriculture fleet with gas powered tractors, there are many irresolvable uncertainties regarding implementation on a mass scale. In an energy-depleted future, conversion to gas-driven engines, if it occurs at all, is likely to take place in a disorganised and haphazard fashion, and would be completely at the mercy of complex supply chains.

Possibly a better use of biogas would be to generate electricity in on-farm micro generators, and use this to charge batteries for small electric tractors. This at least would have the advantage of using existing proven technology (see below).

Ethanol

Ethanol can be produced from a wide range of plant material. The process is simple and involves the distillation of previously fermented material. Feedstocks in temperate climates include potatoes, sugar beet, and wheat. The large scale production of ethanol has had a number of negative environmental social and environmental impacts. Demand for wheat for ethanol production has pushed up grain prices on world markets, with negative consequences for the world's poor. In South America, the demand for ethanol has led to the increased destruction of tropical rainforests. Ethanol can also be produced from fermented non-plant food wastes such as whey. It can be used in diesel engines, though this is uncommon owing to the higher value of petrol substitutes in today's fuel markets.

The energy return on energy invested depends a lot on the feedstock. In the case of wheat, the gross energy output per hectare is about 30-50 percent higher than for oil-seed rape, although the fuel and other materials inputs into the agricultural side are roughly the same. Although there are considerable other energy inputs associated with ethanol production, these could be met using different fuel sources such as biomass. Ethanol output per ha is about 74000 MJ for conventional agriculture, and probably around 25000 MJ for sustainable agriculture. The lower figure is equivalent to 680 litres of diesel. When agricultural fuel imputs are subtracted, the net yield is about 530-560 litres per ha.

Energy per litre: Diesel 36.4 MJ   Ethanol 23.4 MJ l

The main difficulty with ethanol production is finding room for the extra grain, potatoes or beet in a tillage system geared towards maximum food output. One possibility might be to grow oats for ethanol production, and put this into a four year rotation with wheat. However, this would displace oil-seed rape, which would then have to be incorporated into a five year cycle with potatoes and vegetables. The combined net output of ethanol and biodiesel is likely to be in the region 85-95 million litres. This falls far short of envisaged tillage fuel requirments. Certainly there would be no fuel left over for silage or for the much larger non-agricultural transport sector

Hydrogen

Hydrogen is not so much as energy source as a form of energy storage - it cannot be harvested from the earth like oil or gas but must be created using some other energy source. Currently the main fuels used in the production of hydrogen are natural gas, oil and coal. Collectively they account for some 96 percent of global hydrogen production. Most of the remaining 4 percent is from electricity, using a process called electrolysis. In a fossil fuel-starved future, the production of hydrogen looks to be quite problematic. Biogas is unlikely to be available in the necessary quantities, leaving electricity as the only likely energy source. The efficiency of the electricity-hydrogen conversion process is about 60 percent.

At this assumed level of efficiency, it would take 2.5 TWh (1 Terawatt-hour = one billion kilowatt hours) of electricity to produce the hydrogen equivalent of the estimated 150 million litres of diesel needed for silage and tillage. This is roughly the output from all Ireland's wind farms in 2009.

Hydrogen in gas form has a very low energy density and has to be stored in liquid form (at very low temperatures) or at high pressure. When mixed with oxygen it will explode when exposed to naked flame. The dangers associated with hydrogen mean it requires specialised systems of distribution and storage. However, the real problem lies in the fact tractors are not designed to run off hydrogen. The conversion process (from diesel to hydrogen) would involve completely rebuilding the tractor engine. The alternative to the internal combustion engine, using hydrogen fuel cells to generate electricity (for driving electric motors) is extremely inefficient in energy terms. There are no easy answers. As an alternative fuel for tractors, hydrogen comes a poor last, far behind biogas or electricity.

Other Options

Electricity

Electric tractors were first developed in the late nineteenth century. While some of the early tractors were powered from overhead lines in the same manner as trams or trolley buses, most later models were battery powered. Electric tractors enjoyed a brief spell of popularity in the latter half of the twentieth century. They have several advantages over internal combustion engine (ICE) driven machines, notably the high torque at low speed. Also, the weight of the batteries tends to be more of an advantage than a disadvantage, as this makes the tractor more stable and provides better traction. Generally, electric tractors have power rating of between five and fifteen horsepower. This is very small compared with modern four wheel drive ICE tractors, which typically are in excess of 100 hp. However, ICE tractors of under 25 hp are used worldwide in niche applications.

Many electric tractor production lines have ceased to operate since the early to mid 1990s. One factor in the fall in popularity was the high cost of electric tractors compared to ICE driven machines of comparable size. Another complaint was the limited energy storage capacity of the batteries: about 1 kWh per 1 kW of motor capacity (in other words, at maximum power output, the batteries would be fully discharged in one hour). On the plus side, battery powered tractors can avail of a multitude of different energy sources, providing these can be converted into electricity.

From an Irish food security perspective, the main difficulties associated with electric tractors would be the level of capital investment required in order to establish a country-wide fleet, and the limitations of the technology in terms of power output and battery storage capacity. While these latter limitations could be circumvented by careful deployment, the economic hurdle remains considerable. Given their small size, the number of tractors required could easily exceed 100,000.

Stationary engines

From the early nineteenth, stationary engines were used for pulling ploughs and for driving other agricultural equipment. The early ones were steam powered, and used a variety of fuels including wood, peat and coal. Some later models were driven by oil, gas or electricity. Stationary engines were unwieldy and awkward to use, and represented something of a transitional phase of technological development. Their use was generally discontinued as soon as something better - namely stream-driven tractors - came along. Contrary to the general trend however, their deployment in agriculture has continued to this day (albeit on a sporadic basis) in many parts of the developing world.

It is unlikely this technology will have any significant future role in tillage in Ireland, save in very specific circumstances (localities with generous wood or other solid fuel resources for example) where there are clear advantages over the other options available. However, stationary engines may find an important niche role in other food production-related activities, such as threshing, grinding and so on, as they can avail of a wide variety of fuel sources. These types of activities could also be carried out using equipment powered by electricity or driven directly by the wind or hydro power.

The Role of Working Animals

Disclaimer

I make no claim to be an expert on work animals. Therefore, the conclusions reached in this section on animals should be regarded as being of an untested nature. Those who are more knowledgeable of the specifics concerning breeding, utilisation, and other matters touched upon here may wish to challenge some of the estimates offered. If this proves to be the case, it would be helpful if any revised estimates are fully explained, in order that future work of a similar nature can more accurately assess the working animal resource.

Background

The possibility that working animals may have any role in post-oil Ireland may come as a surprise to many younger people. Historically speaking however, Ireland is only two or three generations removed from a world in which the horse was the energy source par excellence in both agriculture and transport. This world continued until less than 40 years ago in some parts of Ireland.

In more recent times car ownership has replaced the horse and cart, while tractors have superseded the use of the horse in agriculture. However, as Ireland moves into the post-oil era, falling availability of vehicle fuels will render much of the contemporary transport infrastructure redundant. Most likely people will travel much less, eat a far greater proportion of locally produced food, and rely far less on the purchase of consumer goods in order to achieve life-satisfaction.

Whatever transport does exist in the future will probably go far slower, and less often. People will strive to live close to sources of employment, and will rely heavily on walking and cycling to get around in their local area.

This does not answer the bigger questions of how essential goods – which of course include food and fuel - will be transported, or how agriculture will fare. For instance, what would Ireland do if there was no fuel for tractors? The research carried out so far suggests that post-oil Ireland would be unable to produce sufficient biodiesel to run its current tractor fleet, never mind service the wider transport sector. So what are the alternatives? How realistic is it for Irish agriculture switch back to animals?

Assessing the animal resource

It is little over half a century since Irish agriculture began the transition from animal power to tractors. Working horses continued to be used until the 1980s on some small farms, and even later in a few cases. In recent years there has an increase in interest in using horses in agriculture and logging. However, the total number of working horses in Ireland at the present time may be as little as 100. In order to assess the potential for using animals for tillage a number of questions must be answered. These include the following:

The total area of land to be tilled each year

The number of working animals necessary to till one hectare

The area of land needed to feed one working animal

The initial number of stock

The age at which animals can start having young

The age at which animals become infertile (unable to bear young)

The average number of successful pregnancies per animal

The typical maximum working age

The ratio of males to females in the working stock

Area of tillage

The area of tillage has already been estimated at 900,000-950,000 hectares (ha). However, not all this land would be tilled in any one year, as some land would be left fallow. The average annual tillage can be assumed to be 675,000-750,000 ha. However, there will be considerable variation in the level of activity required between different parcels of land, as this will depend on the type of crop, methods of cultivation, soil type, inclination (steepness), and other factors.

Oxen

Although the horse was the tillage animal of choice in Ireland in the nineteenth and early twentieth centuries, oxen are still used today in many countries worldwide. Oxen are simply bovines trained as draught animals. While castrated males are often preferred for use as oxen, cows (female bovines) and bulls (uncastrated males) are also used.

At different times, oxen have been used for ploughing, pulling logs from forests, drawing carts or wagons, and for powering machinery for threshing and/or grinding grain, and for other food-related purposes. Oxen are typically used in pairs: one pair might be used for pulling a small plough while addditional pairs would be added for heavier work. For really heavy tasks, large teams of a dozen or more animals might be used. Oxen are often stronger than horses and can work longer. Having a lower centre of gravity they can also pull heavier loads. They also have a reputation for being more sure-footed than horses in difficult terrain.

Oxen were the first animals to be used for labour in Ireland. It is believed they were first brought to Ireland about 4000 BC. Their use in agriculture probably peaked between the twelfth and fourteenth centuries but continued until the early nineteenth century. At a ploughing championship in County Clare in 1805, two oxen were shown to be "*equal* to *the best pair of horses in the field*" (Statistical survey of the County of Clare 1808). Hely Dutton, the author of the Clare survey, felt that the widespread prejudicial view of oxen was mainly due to unfair comparisions being made "*between large sluggish oxen, ill-fed, and medium sized quick-step horses fed with oats twice or three times a day*".

Dutton felt sufficiently agrieved by the poor treatment of oxen to add "*The proper feeding of working oxen is generally most shamefully neglected, and falls most deservedly on the hard-hearted niggard his owner: if they get hay, they are generally thought to be uncommonly well fed; no wonder, therefore, that they are slow in their movements. What sort of step, and for what continuance, would horses have, if fed in spring with hay alone?*"

The reasons for the demise of oxen in agriculture in Ireland are complex. The gradual shift to horses that occured from the Middle Ages onwards was partly due to the greater usefulness of the horse for transportation. Also, agricultural practices in Ireland were strongly influenced by trends in England, where systematic breeding of horses had led to the development of large animals particularly suited to agricultural work. The association of oxen with the more primitive agricultural societies of the past may also have contributed to their demise.

Within Europe, oxen may still be found in some locations in the Balkan region, Iberia, and in the former Soviet Union states. Although some specific breeds are favoured for tillage, this does not necessarily preclude the use of other breeds, including some of those commonplace in Ireland today. Oxen have several other advantages over horses, the most obvious one being that beef is commonly eaten in Ireland whereas horsemeat is not. Surplus calves can be eaten.

Another advantage is that bovines can generally begin breeding at a younger age than horses. This significantly shortens the time period needed to build up critical numbers. Additionally, the large number of cows in Ireland at the present time makes it possible for a sizable herd of working animals to be developed in only a five or six year time span. On the downside, the lack of familiarity in contemporary Ireland with the use of oxen for labour is likely to present a serious obstacle to the development of this resource, especially in the short to medium term. It may be that oxen will only be considered when all other avenues have been exhausted.

One thing is certain, this will not be the last word on the use of oxen in agriculture in post-oil Ireland.

Horses

The horse population in Ireland is currently in the region of 75,000-100,000 animals. The vast majority are bred for racing or used for leisure purposes. Generally speaking they would be unsuitable for tillage purposes, having been bred for characteristics such as appearance, speed, and suitability for riding rather than pulling agricultural implements. Nevertheless, the existing horse population can be regarded as a potential resource, even if used only as breeding stock.

A horse has a potential working life of 20 to 25 years, though the average would be somewhat less. Mares (female horses) can produce young on a fairly regular basis until 17 or 18 years of age, though certainly not every year. Although young mares are sexually mature from their second year, early pregnancies may compromise the later development of the animal. It is assumed that mares used for breeding purposes will only begin bearing young from the age of five.

Estimates of the area of land that can be worked by a horse vary from two and a half to nine hectares (ha) per animal. The wide range of figures may reflect the variation in crops grown, rotation systems and styles of tillage practiced, as well as the breed and size of horse used. Owing to the high rainfall in Ireland, and the preponderance of heavy soils, tillage capabilities may be quite modest. Therefore, it is assumed that on average, one working horse will work four ha of land. This indicates that around 170,000-190,000 working horses would be needed to work all of Ireland's future tillage land. If anything, this figure may be too conservative.

An examination of CSO data shows the average horse and pony population to be 446,000 between 1900 and 1950. The proportion of this number actually used for tillage purposes is not known. However, many horses of this era would have been used for transport or employed in forestry. As horses may also be required for these activities in the future, the numbers employed in tillage are unlikely to represent the total number of working horses needed in Ireland.

The next question is how long would it take to ramp up horse populations to the desired level? This depends of course on the starting numbers. Simple mathematical modelling suggests that a breeding programme beginning with 500 mares and 50 stallions will take 35-40 years to reach critical numbers (say 250,000 working animals). The lesser figure represents the time required under optimal conditions, and is contingent on an annual horse population growth of about 20 percent. These estimates may be on the conservative side.

Clearly a lead time of this duration or longer is problematic. While it may be possible for the breeding programme to begin with larger numbers of mares, this probably precludes pure-bred stock, owing to the scarcity of available mares. One compromise may be to use mares (of non-working breeds) already in Ireland for breeding purposes. Further work is needed in this area to establish the viability of this strategy. If successful it would enable working horse numbers to be ramped up to the desired numbers within 15-20 years, once breeding commences. Given the lack of appreciation in official circles of the potential strategic importance of work horses, it may be concluded that the starting point is still a number of years away. This indicates that although the long term potential is there, horses will only play a minor role in national food security in the short to medium term. However, at local level, where stock levels are quickly built up, work horses may be of major importance. From a strategic perspective, both oxen and horses should be considered for use as work animals.

Human Labour

Although horses were widely deployed in agriculture in nineteenth and early twentieth century Ireland, considerable areas of tillage were undertaken by hand, particularly on farms with very small fields or difficult ground unsuited to horse-drawn equipment. Also, many subsistence farms in Ireland did not own a horse.

The maximum area tilled by hand in Ireland is not known, but may have exceeded 400,000 ha (the current area under mechanised tillage) on occasion during the mid nineteenth century. During these times, the population either produced the food it needed or starved. Although the population in Ireland at that time was much higher than it is today, people were also accustomed to hard manual work.

The area of tillage that can be managed by hand on a part-time basis can be assumed to be in the region of 0.02-0.06 ha (200-600 m^2) per household, although considerably more in some cases. In the past, individual allotments were up to one quarter of an acre (0.1 ha) in size. A household committed to full time food production can be expected to till 0.1-0.5 ha. In the nineteenth century, it was not uncommon for rural farms to till one hectare or more by hand, with a single Irish agricultural labourer tilling up to 0.4 ha (1 acre). However, life was very hard.

The average household size is currently 2.8 persons. This represents an all time low in historical terms. Household size can reasonably be expected to rise in the next decade, as economic and resource-related circumstances mitigate in favour of pooling individual resources. By 2020, the average may be 3.5- 4.0 persons per household. These figures correspond to the average household sizes in 1986 and 1966 respectively. Given an estimated population of 4.8 million, this indicates Ireland will have 1.2-1.37 million households.

It is assumed that the average tillage/land utilised per part time household is 0.04 ha, while the corresponding figure per full time household is estimated to be 0.2 ha. Modern no-dig methods have helped reduce the labour requirements of small scale tillage, so these estimates are quite modest.

The number of households engaged either full time or part time in food production in the future is hard to estimate, but for the sake of this exercise is assumed to be 100,000 and 300,000 respectively in 2020. The full time households would include the farming population from farms with no other forms of tillage, plus a high proportion of all other rural dwellers, plus a smaller number of town dwellers with access to sufficient land. The part time households would be mainly made up of urban dwellers. These households would have allotments, or be involved in cooperatively managed agricultural projects situated close to centres of population.

The hand tillage is estimated as follows

Full time households: 100,000 x 0.2 ha =	20,000 ha
Part time households: 300,000 x 0.04 ha =	12,000 ha
Total	32,000 ha

This figure does not include the land in private gardens. In this context, 'full time' implies at least one person per household engaged full time in food production, but does not necessarily preclude other members of the household having different full time work.

Outcomes

The likely outcome is that Ireland will find it difficult to achieve the level of tillage necessary to feed its population in the post oil era. There is massive uncertainty whether there will be sufficient fuels available to run tractors and other agricultural machinery. While biogas may provide a partial solution, this is contingent on the fuel conversion of most of Ireland's agricultural machinery. This will be difficult to accomplish in a climate of energy scarcity and (presumed) economic hardship

At the same time, it will not be possible to ramp up working horse numbers to level capable of replacing tractors for several decades. While oxen could help fill the gap, this solution is likely to meet considerable resistance owing to the association with backwardness and primitive societies, which in turn will lead to the animal resource not being developed to best effect. The only remaining option is to resort to hand methods of cultivation and here the constraints are two fold: firstly the modern trend away from manual work and secondly the physical limits of human endeavour. Although the area of hand tillage outlined above (32,000 ha) is modest compared to the total tillage needed, it represents a full time commitment from one twelfth of the nation's households, and a part time commitment from twice as many again. Although it would be possible for far greater areas to be tilled by hand, this would involve the total restructuring of society towards labour intensive methods of food production. Essentially Ireland would be obliged to become an agrarian society once again.

Mitigation measures

There are a number of measures that, if taken, will considerably improve the Ireland's food production capability. Some could be initiated and developed relatively quickly while others are longer term strategies that will only yield benefits far into the future. The menu of options described below is by no means exhaustive, but gives a flavour of the type of creative thinking that is needed. No attempt has been made to prioritise the different options.

Pilot projects for Anaerobic Digestion

Foremost of these is the establishment of pilot projects in the silage AD sector, as this will determine the viability of the silage biogas resource. The object should be to develop farm or local community-run projects that can produce biogas for transport purposes, and that utilise the gas in local agricultural enterprises (initially in mixes with biodiesel but ultimately in gas-driven engines). If successful, such pilot projects will encourage the further expansion of the sector. A useful complementary development would be the setting up a facility capable of producing gas-powered engines suitable for use in tractors. This reaffirms the importance of re-establishing steel production capability in Ireland.

Horse Breeding Programme

The second measure is to set up a work horse breeding programme that can utilise the existing horse population as breeding stock. This will involve importing stallions of appropriately work horse breeds, or using artificial insemination, or both. The current mare population in Ireland is made up of breeds intended for racing or leisure purposes, and the size of these horses will determine the breeds suitable as semen doners. It may take several generations to establish a cross breed with the right characteristics for pulling agricultural implements. However, this will still allow useful numbers of work horses to be built up far more quickly than if the breeding programme is begun with very small numbers of pure-bred workhorses.

Oxen Pilot Project

While there appears to be a growing interest in the use of work horses in agriculture, this interest has not extended to other work animals. The dominant role of the horse in recent pre-industrial agriculture in Ireland has largely eradicated the cultural memory of oxen. However, the use of oxen continues to this day in various corners of Europe, and this represents an opportunity for the acquisition of knowledge and expertise. Some of this expertise may have inadvertently arrived in Ireland with the wave of immigrants from Eastern Europe. A good starting point would be the establishment of a small oxen-based tillage enterprise, possibly using one of the older, hardier breeds of cattle.

Development of less energy intensive methods of food production

This could take many forms. No-dig methods of crop production may enable much larger areas of land to be managed by hand. Such methods are already practiced at micro scale in Ireland. Advocates of no-dig systems point to the lower labour inputs and also argue that biological soil structures suffer less disruption, leading to better nutrient uptake, lower nutrient losses, and larger yields. Mulching, another component of no-dig systems, greatly assists in weed control, thus reducing labour requirements even further. Further research in this area would be helpful, particularly in making direct comparisons between dig and no-dig systems. One concern about no-dig systems is the possible proliferation of flatworms - non-native earthworm predators that have decimated earthworm populations in some places.

Other options for low energy input food production include nut crops and low density livestock farming. Inputs from these sectors may help reduce the tillage requirement. These areas will be examined in more detail later.

Increasing yields

It may be premature to assume that all the potentially available tillage land will actually be needed for crop production. Estimates of sustainable outputs are largely based on agricultural yields attained during the early inter-war period, when the use of artificial fertilisers would have been relatively uncommon in Ireland. These yields may not be an accurate reflection of the outputs possible in the future. Longer term crop rotations involving rest years may significantly increase yield without compromising soil fertility. However, it must also be acknowledged that the recycling of human manure was a significant contributor to soil fertility in the past. Although the type of sewage disposal systems currently employed in Ireland permanently removes human manure from the nutrient stream, the recycling of human manure is likely to play a crucial role in maintaining soil fertility in the future.

Another important avenue of investigation concerns the use of biochar (charcoal produced from biological sources) in agriculture. There is growing evidence that the incorporation of biochar into soil has significant long term benefits. These include enhanced nutrient uptake, reduced nutrient leaching, increased micro organism activity, pH balancing, and improved drainage. The use of biochar in agriculture goes back thousands of years. The best known examples are the Terra Preta soils in the Amazon basin. These soils were created by pre-Christian era agrarian societies. The most notable distinguishing feature of these soils, compared to the soils of the nearby Amazonian rainforest, is the high charcoal content. Human artefacts recovered from these soils indicate these soils were cultivated over a period of 1500-2000 years. The civilisation that flourished during those times is thought to have been decimated by disease introduced by Europeans during the 16th century. It appears the complex systems of agriculture were simply abandoned as the few survivors fled into the rain forest. Even after many hundreds of years of disuse, the soils have retained high levels of nutrients, and show little sign of reverting back to the poor mineral soils more typical of the Amazon rainforest. One possible limiting factor with regard to the widespread deployment of biochar is the energy required to harvest and process feedstocks. In some cases, this could be considerable.

The issue of sustainable agricultural yields - including nutrient cycling and the use of biochar - will be examined in much greater detail in a subsequent document.

Preliminary Conclusions

Many discussions involving food security have focussed on the question of land availability, rather than the methods of production. The debate on land availability should not be confined to the question of how much, but must address the issues of access, management and ownership. Even if these issues are resolved, there still remains the problem of how to provide energy inputs needed in order to make the land productive. Further, the two problems are interlinked, as the degree of land access will in turn assist or delay the establishment of community-led demonstration or research projects. Research has a critical role to play in determining the best utilisation of human, animal, fuel and land resources, yet paradoxically this research may be slow to happen owing to poor utilisation of land, human and energy resources at the present time.

What is clear is that there is no easy or single solution that will enable agricultural production to be maintained at levels capable of feeding the entire population. The solution will be complex, involving many different energy inputs and a wide range of interlinked strategies. While some of this complexity will naturally evolve in response to circumstances, a failure to examine the widest possible range of options now will inevitably affect the outcome in a negative way. In many ways this mirrors the risks posed by the overall lack of preparedness in society for fossil fuel depletion, global supply chain disruption, and the inevitable ending of a two centuries long era characterised by increasing availability of energy.

Further information and feedback

This document should be treated as a work in progress and will be updated on a regular basis. It will eventually form part of a much broader treatise on food security that will be published later this year. Articles wll be posted on my own personal website: www.andywilson.ie

Comments and contributions are especially welcome.

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Sources: all raw statistics for Ireland were obtained from the Central Statistics