CARBON-NEGATIVE PRIMARY PRODUCTION: ROLE OF BIOCARBON AND CHALLENGES FOR ORGANICS IN AOTEAROA/NEW ZEALAND

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Abstract
In this review we critically examine the current status of industrialised and organic agriculture in New Zealand in relation to carbon-capture and some of the key environmental, economic, and political drivers for change. In the light of the recent international interest in *Terra Preta*, particular attention is given to indigenous agroecologies, advances in the technology of biocarbon production, and the role of biocarbon in increasing soil carbon sinks. Research gaps are identified and some of the tools and design principles are described for moving from both fossil-fuel dependent industrialised production, and compost-dependent organic production, to biomass based carbon-negative primary production. It is proposed that carbon-negative primary production will play a crucial role in reducing atmospheric carbon-dioxide and will drive the emergence in New Zealand of a post fossil-fuel economy.

Key words: carbon-negative primary production, industrialised agriculture, organics, biocarbon, charcoal, flash-carbonization, greenhouse gas emissions

Introduction

Agriculture has far-reaching influences on ecosystems, economies, and societies (Freudenberger 1986, Pretty et al. 2000). In the second half of the 20th Century, an increasing emphasis on economics rather than ecology, and the availability of cheap petrochemicals, fuelled the industrialisation and intensification of agriculture. Reactionary movements (e.g. Organics, Biodynamics, and Permaculture) have so far been unable to reverse the predictable soil losses, salination, chemical contamination, and a dietary-induced epidemic of obesity. Driven by a belief in the unlimited power of technology, seed-selling corporations, scientists, and the U.S. Government proposed that the genetic modification of crops and food was the ultimate panacea to the environmental and social problems resulting from the industrialisation of agriculture. In the first decade of the 21st Century, however, the predicted global shortage of cheap, easily extractable oil, and the cost of reducing greenhouse gas emissions will require fundamental changes in economic considerations. Food-safety and health concerns arising from the potential of factory farming to spawn global epidemics of animal and human-diseases raise additional political pressures, particularly in Europe. The direct and indirect economic costs of global- warming may be the Achilles heel of industrialised agriculture. Each of the reactionary movements of the 20th Century raised questions about the main features of industrialised agriculture. None of them, on their own, have been able to provide a foundation for the radical changes required to prevent global environmental and social disasters. Biomass-based carbon- negative primary production may provide a sufficiently broad-platform to drive the radical changes necessary. New Zealand (NZ) is one of the few OECD countries with a biomass-dependent economy and fossil-fuel dependent agriculture. It is in a unique position to lead these changes.

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ISSN 1177-4258

NZ, Kyoto Protocol, and agricultural greenhouse gas emissions

Dairy farming is currently NZ's largest foreign-exchange earner, with Fonterra, its largest dairy company, responsible for more than a third of the international trade in dairy products (MAF 2002a). In the U.S., grain previously used for dairying is increasingly being diverted to biofuel production (Independent 2007). The unexpected competitive advantage of grass over grain-fed dairy leaves NZ, as a signatory to the Kyoto Protocol under the UN Framework Convention on Climate Change, with the unique dilemma that 50% of the country's greenhouse-gas emissions come from agriculture (New Zealand's Climate Change Solutions 2007). Although not the largest contributor, substantial quantities of methane are produced by rumen-microbes, and nitrous oxide is emitted from the denitrification of urinary-nitrogen on grassland soils. Methane and nitrous oxide have 21 and 310 times, respectively, the greenhouse gas equivalence of carbon dioxide (IPCC 2001a, 2001b). Further, as economics currently favour dairying over forestry, conversion of mature and immature production-forests to dairy-pasture is exacerbating greenhouse gas emissions, and removing carbon sinks (McCarthy 2005). Initial data also suggest that the intensification of dairy farming over the last 20 years has resulted in large losses to the atmosphere of soil-carbon and nitrogen (Schipper et al. 2007).

In the face of the harsh economic realities of international global-markets, the NZ Government has maintained a firm commitment to meet its Kyoto obligations. In 2006, the NZ Government unveiled a bold new national carbon neutral vision. In September 2007, the Ministry for the Environment released a policy statement on solutions to climate change which outlined the broad framework of an emissions trading framework (New Zealand's Climate Change Solutions 2007). The Ministry of Agriculture and Forestry's (MAF) comprehensive action plan is backed by substantial additional Government funding (NZSFA Action Plan 2007). Because of the substantial contribution of agriculture to the emission of greenhouse gases, the success of this policy will depend on how effectively it is applied to primary production. Full rural implementation would have wide-ranging social and economic as well as environmental ramifications. This initiative is potentially one of the most radical policies ever implemented by a NZ Government. However, the full benefits of such an initiative will require substantial changes in production systems, focussing on innovative research to develop effective measuring systems and objective standards. A successful public and private investment in primary production, combined with a branding and marketing strategy, could deliver huge dividends to the NZ economy.

Carbon-neutrality is a goal that makes perfect sense, given the emissions focus of the Kyoto Protocol. Under the current cap and trade system of the Kyoto Protocol, no value is assigned to the soil as a carbon-sink. This means that apart from forestry, which has its own issues at harvest, primary production incorrectly appears as if it is always a net-emitter of greenhouse gases. In fact, perennial crops such as kiwifruit and grapes may come close to carbon-neutrality once the carbon-sink value of roots and stems are properly accounted for. The sums would be even more interesting for perennial organic systems that have eliminated the fossil-fuel costs of fertilisers, herbicides, insecticides, and fungicides. Dairy farming is not in such a favourable position. However, the net-emission value of dairying is probably over-inflated because the carbon-sink values of the soil, plants, and animals are not accounted for. The Ministry of Agriculture and Forestry (MAF) has moved swiftly to ensure that the Government has accurate, quantitative greenhouse-gas footprints for primary industry (Government investment initiatives under the plan of action 2007). The collation of existing data will almost certainly reveal qualitative as well as quantitative gaps in the understanding of the size and half-life of soil-carbon pools. Further debate is needed on whether the same greenhouse-gas value should be assigned to carbon emissions that are derived from biomass-carbon as those assigned to emissions from fossil-carbon. To better answer this question, a quantitative understanding is required of the fast biological cycling that occurs when biomass is added to the soil as mulch, compost, and other organic amendments (Coleman et al. 1983).

A key wealth-creating policy of the NZ Government is the application of technology to agriculture (MAF 2002b). The technology proposed in 1999 was generally understood to be

GM-technology. The diversion of substantial government science funding to GM-research diverted funding away from and resulted in a loss in research capability in sustainable primary production, with virtually no investment in developing new, more ecologically-based production systems. Important research breakthroughs in soil science were made overseas in areas where NZ was once a research leader. The following three developments, in particular, are directly relevant to understanding the range, size, and half-life of soil-carbon sinks.

First, the rediscovery of Amazonian Dark Earth (*Terra Preta de Indio*) rekindled an earlier research interest in the longevity and effect on soil fertility of charcoal mixed with various organic and inorganic materials and added to wet oxisol soils (Glaser et al. 2001, Lehmann et al. 2003). It also stimulated a much wider public interest in soil organic-matter. Second, an English summary of Japanese research showed, in some soils and for some plants, that biocarbon in combination with reduced amounts of fertiliser, increased plant growth compared to standard amounts of fertiliser (Nishio 1996). Third, a mycorrhizal glycoprotein named glomalin was discovered in considerable quantities in a previously discarded soil fraction (Wright & Upadhyaya 1996). Glomalin promotes soil-aggregation, resists microbial breakdown, and has a significant soil half-life (Rillig et al. 2001). Thus, both biocarbon and mycorrhizae have the capability of sequestering a substantial amount of fixed carbon. This carbon has come from atmospheric carbon dioxide fixed by photosynthesis and transferred as sugars from plants to root fungi forming a symbiotic association known as mycorrhizae.

Although a standard method for analyzing the fixed carbon-content of biocarbon has been described (Antal & Grønli 2003), more research is required to quantify the glomalin levels, and biocarbon and glomalin half-lives in a range of soils and climates under various production regimes.

Biocarbon (Charcoal)

Charcoal has played a crucial role in the industrial and electronic revolutions (Antal & Grønli 2003), and is defined as the residue of solid non-agglomerated organic matter of vegetable or animal origin that results from carbonization by heat in the absence of air at a temperature above 300°C (Emrich 1985). When charcoal is heated (“carbonized”) above 800°C it loses any remaining volatile matter and becomes nearly pure carbon. The term biocarbon was proposed to include charcoal and carbonized charcoal (Antal 2004). The flash-carbonization process, first described by Antal (2004), revolutionises charcoal production. At elevated pressures (1MPa) and temperature (400^{o}C) the process is extremely fast, is catalysed by water, is highly exothermic, and the yield of fixed-carbon attains the theoretical yield at thermochemical equilibrium. The latter is achieved by holding the pyrolytic vapours captive and in contact with the solid products, where they are converted into biocarbon (Antal et al. 2000). Biomass can be converted to biocarbon in less than 30 minutes with the generation of substantial excess energy over what is required for ignition. By completely altering the economics of biocarbon production, flash-carbonization is a critical step in developing an economically viable biocarbon fuel-cell (Antal et al. 2003, Nunoura et al. 2007).

In NZ, policy advice to the Government on carbon-negative primary production needs to be based on a thorough understanding of carbon sequestration and stabilisation in soil, its implications for soil productivity and climate change, and the new pyrolysis technology and its potential to reduce fossil-fuel use (Goh 2004, Antal 2004). Pilot-scale research showed that under water-stress conditions in West Australia, large amounts of biocarbon with reduced amounts of soluble fertiliser, and low concentrations of biocarbon with mineral fertilisers and microbial inoculants increased wheat yields over standard soluble-fertiliser treatments (Blackwell et al. 2007). Benefits were also demonstrated on a pilot scale in New South Wales for field-grown wheat and soybeans (Van Zwieten et al. 2007). A shift away from fossil carbon dependent primary production may not only be possible, but could make good economic sense. Any future carbon-credit value derived from the addition of biocarbon to the soil and from increasing soil organic-matter *in situ* could have significant economic benefits. More field-scale trials are required to quantify this.

In the ‘organic movement’, some have questioned why composting, a process that produces greenhouse gases, would have a place in sustainable agriculture, particularly when biocarbon can sequester carbon in the soil for much longer than soil-humus (Baldock & Smernik 2002).

Further, flash-carbonization is a net-producer of energy that can replace fossil-fuels, and it uses agricultural and forestry wastes that are not or cannot be easily composted (Antal & Grønli 2003). The carbon-dioxide generated from pyrolysis could be used to enhance the growth of algae used to grow oil for the manufacture of biodiesel.

Accurate figures are needed on the quantities of pyrolysable biomass available from the wastes of primary production and forestry, the fixed-carbon yield of different biomasses, the costs of biocarbon production and addition to the soil, the net-contribution of fixed-carbon to reductions in atmospheric carbon-dioxide, and the agronomic costs and benefits.

Biocarbons in soil

Given the relatively low cost of flash-carbonization, investigating the potential benefits of biocarbon on soil fertility and microbial ecology becomes agriculturally relevant. Ecosystem-wide effects range from improving water-holding capacity and porosity, enhancing cation-exchange capacity (in combination with organic material), increasing levels of beneficial bacteria, providing a refuge from predation for mycorrhizal fungi, and enhancing beneficial soil-fauna such as earthworm populations (Gundale & DeLuka 2006, Kothamasi et al. 2006, Sato 1990, Van Zwieten et al. 2007). In combinations, this array of physical and biological effects has the potential to reduce NPK fertiliser dependence, reduce soil-denitrification, and to improve the activity of beneficial microbes (Blackwell et al. 2007, Van Zwieten et al. 2007, Hill et al. 2007). Elucidation of these effects requires further research on the physical chemistry of hydrated, charged, microporous surfaces, microbial ecology, agronomy, and agroecology.

Much of the critical chemistry in soils takes place on the extensive charged nano-porous surfaces in contact with water (Theng 1979, Wiggins 2004). Although the reaction volumes are enormous, their extension of no more than a few nanometres from the solid surface makes them extremely difficult to probe. Consequently, bulk measurements of pH and cation exchange capacity often bear little relationship to the chemistry that takes place in these thin but extensive interfaces. Physical models have been developed and used to empirically probe the properties of these interfacial-layers (Wiggins 2004). It is likely that further experimental work based on these models, and using biocarbons produced from different biomass-sources and under different pyrolysis conditions, will elucidate what are currently puzzling anomalies. Substantial areas of ignorance remain about even the most fundamentals areas of how biomass, let alone biocarbons, functions in the soil. It is not that there is anything mystical about the physicochemical and biological effects of biocarbons, it is just that in a world of abundant cheap fossil fuels they have rarely been considered to be of importance.

Which biocarbon for what use?

The complex kinetics of biocarbon ‘devolatilisation’ (formation and loss of gaseous species from the parent biocarbon) have been described (Várhegyi et al. 2002).The maximum reactivity of bamboo biocarbons, due to the presence of free-radicals, is achieved using pyrolysis temperatures below 475^{o}C (Asada et al. 2002). The reactivity of these biocarbons means that they are capable of absorbing oxygen that under certain conditions can result in self ignition (Firth 1892). At temperatures above 450^{o}C, nanometre-scale micropores attributed to the formation of microcrystalline graphite are formed (Kurimoto et al. 2004). As the pyrolysis temperature increases above 450^{o}C, the reactivity of biocarbons is increasingly characterised by the properties of water condensed in nanometre-sized pores (Sugimoto et al. 2007). Given that the normal temperature range of biocarbon pyrolysis covers both those for maximum free-radical formation and the evolution of microporous structure, the effects of biocarbons in the soil are likely to be determined by the complex interaction of these two components. Evidence is emerging that biocarbons produced from different biomass-sources, and by different processes, can have very different properties. Our own preliminary experiments (Hill et al. 2007) concur with those of others (McClellan et al. 2007) in finding that in some soils, biocarbons prepared by flash-carbonization were beneficial to plant growth, whereas those produced by standard methods were not. Research is needed on how different biomass-sources (plant or animal, leaf or wood, bone or feather), pyrolysis-process conditions (pressure, temperature) and subsequent activation, affects the benefits of biocarbons in soil. Care also needs to be taken to take account of and manage the effects on plant-growth of materials other than biocarbon, such as calcium in pyrolysed paper industry wastes, and in pyrolysed chicken litter.

The rediscovery of the importance of the soil as a carbon-sink is a reminder of the quality of the early work on humus (Howard & Wad 1931, Waksman 1936) and, in particular, the clear demonstration at farm-scale that biomass-sourced carbon and nitrogen added to the soil can be sufficient to improve soil fertility, plant and animal health, and productivity (Howard 1940). We have come almost full-circle with the mounting costs of environmental degradation and greenhouse-gas emissions from more intensive agriculture driving the demand for research to find biological substitutes for the most damaging pollutants and fossil-fuel derived inputs (Williams 2004). Biocarbons extend the range and possibilities for use of biomass in soil. Considerable work remains to be done, however, to establish the effects of various organic amendments on different soils, in different climates, and under different farming practices.

Biological fertilisers

Cheap, soluble fertilisers made possible more intensive crop production, encouraging the treatment of soils as chemical repositories for plant-nutrition, to be topped up with fertilisers and amended with lime whenever necessary (O'Connor 1990). The high fossil-fuel cost of the production of soluble fertilisers, the environmental damage from nitrogen-'leakage' into waterways, and greenhouse-gas production from the denitrification of urine patches on soil (Hendrickson 1996, EBOP Technical Report 2004, Suter et al. 2006) have focused attention back on the role of biological components in maintaining soil fertility. The critical importance of mycorrhizae as the 'living bridge' between fertile, humus-rich soil and plant roots was realised last century (Howard 1940). A recent review suggests that mycorrhizae might not be the only soil microbial associations capable of acting as a living bridge between various soil nutrient and carbon-pools and plant roots (Rillig et al. 2007). Since Howard's work, research has shown that mycorrhizae provide plants with additional water and phosphate accessed more effectively and from a greater volume of soil than is possible by plant roots alone (Smith & Read 1997). It has also been shown that mycorrhizae are able to transfer nitrogen to plants from organic matter, and mineralise potassium (Hodge et al. 2001, Yuan et al. 2004), with some evidence that the translocation of nitrogen, potassium and magnesium depends on the simultaneous translocation of phosphate in some mycorrhizae (Jentschke et al. 2001). Some research suggests that the benefits of microbial symbiotic relationships may be lost in well fertilised soils (Morgan et al. 2005).

There is considerable debate about the mechanics of how and from what sources plant roots and mycorrhizae access phosphates. It is clear that organic phosphate sources are important, and that there are differences in the ability of plants and mycorrhizae to access phosphate from the same source; and some research suggests that plants and mycorrhizae may access phosphate from different sources (Ghani et al. 2007, Chen et al. 2004, Scott & Condron 2004, Morgan et al. 2005). The promotion of legume growth in response to biocarbons and reduced-fertiliser use in soils where phosphate is the limiting factor in nitrogen fixation is thought to be due to the enhanced uptake of phosphates by mycorrhizal roots (Nishio 1996).

The small amounts of nitrogen fixed by free-living nitrogen-fixing bacteria will never match that fixed by rhizobia in legumes. It may be critical at times of high plant-nitrogen demand, and become agronomically significant if at those times it can be fixed in close proximity and delivered to plant roots. Research suggests that this may be the case in the regeneration of burned-over forests (Berglund 2004). Further research is needed on what combinations of biocarbon, organic material, and microbial activity create environments capable of reducing the oxygen concentration and providing the large amount of energy necessary for nitrogen-fixation. This will only be of agricultural relevance if nitrogen can be fixed in sufficient quantities to make a material difference to crop production at field, orchard, or forest-scale in general, or at times of high demand.

Soil fauna such as earthworms are also likely to play a significant role in keeping key plant nutrients in circulation (Hill 1985, Ruz-Jerez et al. 1992). There is evidence that some earthworm species are fungal-browsers (Lee 1985), so it is not surprising that biocarbon is associated with an increase in earthworm numbers (Siegried Marian's work referred to in Conford 2001, Van Zwieten et al. 2007). Further research is required on the role played by earthworms and other mesofauna in keeping key elements inaccessible to bacterial decomposition, such as the nitrogen in glomalin and chitin in circulation as part of the fast-nutrient cycling that occurs in the rhizosphere (Coleman et al. 1983).

Highly productive healthy crops and animals can be produced without the need for soluble fertilisers and by the careful management of soil organic-matter (Howard 1940). Research reviewed above raises the possibility that biocarbons could offer another option for economically managing bacterial fixers of nitrogen; fungal miners of phosphates, potassium, and movers of water; and the mesofaunal facilitators of fast carbon-cycling.

Plant and animal health

Research showing that some biocontrol rhizosphere microbes are able to induce a general improvement in plant vigour and productivity (Harmen et al. 2004, van Loon 2007) illustrates one mechanism where the addition of organic-matter to the soil can promote plant and animal-health and vigour (Howard 1940). Pioneering organic farmers found that the simplest and most economic way of maintaining populations of beneficial microbes where they were of most benefit was by changing the environment in their favour (Howard 1940, Turner 1952,). Another option is to use living biomass to influence microbial ecologies. The potential of such an approach was demonstrated in a classic study on a *Fusarium*-resistant flax variety that secretes from its roots small amounts of HCN (hydrogen cyanide). The HCN deters the pathogen and favours the biocontrol fungus *Trichoderma* (Timonin 1941). Our preliminary research suggests that some biocarbons work synergistically with beneficial microbes to enhance both the rooting and growth of *Pinus radiata* cuttings (Hill et al. 2007).

Whilst still in its infancy, manipulating the microbial composition of soil ecosystems provides an important component in the biological toolkit for reducing and potentially eliminating the high fossil-fuel costs of insecticide and fungicide production. Although inoculation of the soil with specific beneficial microbes may work, the most cost-effective long-term solutions are likely to be those that change the soil environment in favour of indigenous beneficial microbes and enhance the populations of mesofauna capable of spreading the beneficial microbes in the rhizosphere (Singer et al. 1999).

Organics and carbon negative primary production

Pests and diseases can spread easily in organic monocultures. In New Zealand, varieties of plants commonly used in organic production are those selected to do well with high inputs of soluble fertilisers and the use of insecticides and fungicides for disease control. Animals are generally those selected for high productivity, with little attention to disease resistance, vigour, or food quality. Compost is commonly regarded as a substitute for soluble nitrogen fertilisers, rock- phosphates for superphosphate, and biocontrol agents and natural products are substituted for synthetics. Despite the elimination of many of the fossil-carbon dependent inputs from organic production, there is still a substantial fossil-fuel and greenhouse-gas emission cost in what is substituted to maintain soil fertility and crop, tree, and animal health. In many crops, such as organic kiwifruit, conversion to organics may result in an overall increase in input costs as well as a drop in productivity (MAF 2004). This means that the high retail-premium required to maintain farmer viability for NZ organic kiwifruit significantly limits market size and is a substantial barrier to those considering organic conversion (Harris et al. 1999).

For crops like kiwifruit, where there is a sufficient understanding of crop ecology, physiology, and production, it is possible to identify simple management practices that can reduce the input-costs and improve productivity and quality (Harris et al. 1999). In some soil-types, and for some crops, the use of various combinations of biocarbon with small amounts of mineral fertilisers and/or careful management of the ground cover may completely eliminate the fossil-fuel cost and greenhouse-gas emissions of compost manufacture and spreading (Blackwell et al. 2007, Harris et al. 1999). This may be an anathema to some organic certification businesses. In some circumstances, however, the fossil-fuel cost and greenhouse-gas emissions from tillage and compost manufacture and spreading could be unacceptably high.

In NZ, the required three-year transition to organics is a significant economic barrier for many farmers. We believe there is no rational or objective basis for the length of this transition. Simple tests developed in NZ, and now used internationally, allow farmers to quickly visually assess soil quality (Shepherd 2007). Further research is planned to establish whether such visual assessment systems can be benchmarked against laboratory-based analyses of operationally defined soil carbon and nitrogen pools, and used to establish an objective basis for production standards. Such assessments and standards have potential across a range of soil-types and production systems. Biocarbon, by increasing mycorrhizae levels and thus soil organic-matter protected from immediate bacterial breakdown, has the potential to significantly benefit soil biological activity (Nishio 1996, Wright 1996). Visual assessment of this activity linked to an objective analytical standard, and used in conjunction with existing residue-analysis techniques could revolutionise organic-transition and certification by providing farmers with a clear goal-oriented objective standard.

Carbon negative primary production: a systems-approach to putting it all together

Industrialisation has led to agriculture being treated as an economic activity with an annoying biological component, and with scant regard for environmental and social consequences. The logical conclusion of this mindset is factory-farming, monocultures of genetically engineered crops, and the treatment of pastures as dry-matter generators. Sustainable agriculture requires ecosystem management within specific economic constraints, and operating within the norms of a specific cultural environment. From both an ecological and economic perspective, sustainable primary production will require the intelligent management of both biomass and agroecosystems. This will be driven first by the urgent need to reduce greenhouse-gas production and find biological and solar-based substitutes for fossil-fuels and fossil-fuel-dependent inputs, and second by a political desire for supporting primary production that is ecologically and economically sustainable and socially just (Freudenberger 1986).

It is possible that substantial savings can be made in primary production by implementing relatively simple changes in management practices. In dairy farming, for example, maintaining an on-average greater sward height can substantially increase plant-root depth and soil organic- matter, and the amount of nitrogen able to be sequestered by the extra biomass (Ball 1982, O'Connor 1990). Better soil-drainage, thicker swards, and removal of stock when the soil is waterlogged, would reduce damage from pugging. Biocarbon, delivered to the soil through the cow's digestive system, added during cropping, or added directly to the sward, would increase aeration. In combination, these practices may eliminate the anaerobic, pugged (waterlogged and trampled) environments that are generators of nitrous oxide in NZ winter-wet regions where substantial dairy conversions have and are taking place (O'Hara et al. 2003).

Much can be learnt from the analysis of indigenous agroecosystems. They were extensive, complex, bioregional, and culturally specific (Altieri & Koohafkan 2002). Some systems, such as those in Mexico, continue to be practiced (Lumsden et al. 1990). The best of these systems improved soil fertility without any fossil-carbon inputs (Crews & Gliessman 1991). On some Amazonian soils, the improvements have lasted for millennia (Antal & Grønli 2003). Biocarbons were mixed with a wide and varied range of organic and inorganic materials including fish-bones, shells, cooking juices, and animal manures, pottery-fragments, ash, and limestone, and then added to or mixed into the soil (Erickson 2003, Macnab 1969). Other materials such as alumino-silicate pumice sand in NZ and pottery shards in Amazonia with similar water holding capacity and macro- and micro-porous structure to biocarbons were often used in combination with biocarbons.

The substitution of conventional inputs in industrialised agriculture with organic-inputs inevitably carries with it 'design' costs (Fukuoka & Metreuad 1985, Hill 2006). So too, mere substitution to dependence on fossil-fuels and fossil-fuel dependent inputs, and reduction of greenhouse-gas emissions and environmental pollutants in intensive production systems will have its own residual greenhouse-gas emission and environmental costs assessed (Gliessman 1990, Williams 2004). Ultimately, primary production needs to be redesigned around minimising the use of fossil-carbon by maximising the use of biomass-carbon in ecologically harmonising production systems within total-landscape systems (O'Connor 1990, Williams 2004). Within the EU, radical questions are already being asked and solutions sought through the redesign of production, processing, and manufacturing to better fit with ecosystems processes (Benjamin et al. 2000). Design-solutions have the potential to benefit the environment, rural economies, and communities. In some landscapes this will require a reappraisal of the most appropriate plant- and animal-mixes. The oil mallee project in South and West Australia is an excellent example of the reintegration of elements of the original landscape into current pastoral and arable production systems (Bartle & Shea 2002). Further, the use of biocarbon produced from the spent leaves and twigs after oil extraction, is suggestive of how the wastes from one system (oil mallee) can reduce the input costs in another system (wheat production) (Blackwell et al. 2007).

Given the new imperatives to reduce agricultural greenhouse-gas emissions, perhaps more extensive cropping and aquaculture can be integrated into dairy farming on the Manawatu Plains as suggested by O'Connor (1990). Eel-production on dairy farms, for example, would require clean water. Solid waste from dairy-sheds or herd-homes could be used to grow worms for cheap high protein eel-food. Given new markets, packaging and processing, 'share-eeling' may one day rival 'share-milking' as shared-equity option on dairy farms in the Waikato. In fragile environments such as the North Island volcanic plateau, other ruminants such as alpacas may be integrated with indigenous trace-element concentrating browse species. In Bay of Plenty kiwifruit orchards geese may one day graze the under-storey, or ginseng replace the spray belt..

At a practical level, no single-design solution will fit the processes of all landscapes (O'Connor 1990). New systems will emerge and evolve, driven by careful critical consideration of indigenous ecologies, farmer knowledge, relative economics of composting and biofuel options for organic wastes, differences in the mineralization rates in different soils, the different and combined abilities of microbes, plants, trees and animals to concentrate and sequester key nutrients, taking into account the farming history of the region. Comparatively simple solutions such as changing grazing-regimes in pastoral farming to increasing plant root-depth to increase soil carbon; massive planting of trees; and the incorporation of pyrolysed waste-biomass into the soil may have large multiplier effects on reducing carbon-dioxide levels in the atmosphere. Rather than being a large contributor to the global environmental crisis, agriculture, via a shift to biomass based carbon-negative primary production, may not only be a major part of the solution but, by rejuvenating rural communities and economies, also provide a genuine alternative to fossil-fuel based economies. Organics, by building on the emission-reduction and elimination of soluble fertilisers, insecticides, herbicides, and fungicides, could lead the way. Emission and pollution costs are driving a fundamental rethink of agricultural practices in the much larger non-organic sector. The cost of greenhouse-gas emissions and the need to sequester carbon will drive fundamental changes in agricultural practices. Ironically, leadership seems likely to come from the very co-operative industry bodies in the kiwifruit industry (Zespri International) and the dairy industry (Fonterra Co-operative Group) that the free-market advocates of industrialised agriculture are keen to destroy.

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