Soil Fertility Management –

Towards Sustainable Farming Systems and Landscapes

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In a nutshell: Soil fertility is the capacity to receive, store and transmit energy to support plant growth. These processes require healthy soils – living, self-organising systems with physical, chemical and biological components all functioning and in balance. Continuous use of acidic or salty synthetic fertilisers, insecticides, fungicides and herbicides disrupts this delicate balance. Organic Farming has recognised this, but needs to follow its leaders to active soil fertility management. Carbon, in particular, is of critical importance and needs to be maximised through capture with solar energy through photosynthesis by green plants, and optimum storage and use in the soil. Before we can hope to improve systems, however, we need to understand (1) why they are the way they are, and then (2) how science and practice can help to actively manage soil biology to improve and maintain soil fertility, and achieve more sustainable, healthy and productive farming systems – even on our fragile Australian soils in a highly variable and changing climate.

Problems

The long recommended use of fertilisers, pesticides and other synthetic chemicals to address problems in agricultural production has been leading to poor soil health and resistance in insects, diseases and weeds. More soluble nitrogen fertiliser makes plants more susceptible to diseases and insects, and increases weed problem. As renowned holistic scientist Dr William Albrecht said "*insects and diseases are the symptoms of a failing crop not the cause of it*". The petrochemical solution is not working – all such production systems in the world are on a treadmill, needing more and more chemicals and fertilisers to keep yields up as natural soil processes are increasingly weakened in their role of supporting plant growth. This makes soils and plants dependent on these inputs. Such production systems are not sustainable and we currently harvest the outcomes of the gross oversimplification of fertilisation and 'plant protection' practices.

Agricultural systems have become addicted to the soluble acidic-based NPK fertilisers and this addiction, supported with the then required pesticides and herbicides, leads to soil degradation; thus keeping producers on the 'production treadmill' with 'more on' farming. The humic substances which are pivotal in soil fertility and plant nutrition have gradually been destroyed (Pettit 2006). Humus is the bond between living and non-living parts in soil and is part of the soil organic carbon that has severely declined since cultivation started. Curing any addiction is a slow process, requiring understanding, patience and commitment. This, however, has not yet been accepted by a science world which seems driven by commercial interests. Those in organic-biological farming remain the exception.

The problems arising from the petrochemical approach were first exemplified in Rachel Carson's 'Silent Spring' (1962), which exposed the effects of indiscriminate use of pesticides, and eventually resulted in the banning of DDT. Nevertheless, in spite of this warning, industrial manufacturing and widespread agricultural use of chemicals continue to affect our environment. Consequently, many registered chemicals have since been taken off the market when negatives of long-term use became apparent. Consumers concerned about effects of chemicals on food quality and health will increasingly demand food free of chemical residues. Science is becoming aware that one part per million or even one per billion could be one part too much for many.

To improve soils, farming methods in annual cropping are changing from intensive cultivation to minimum tillage and no-till systems as being environmentally better and with good returns. Such ‘sustainable’ systems, however, are empirical as they are developed without a full understanding of long term outcomes. Impact of associated intensive chemical use is the unknown factor. It is the combined and repeated impact of chemical use that affects the system – factors not tested in product registration process or long-term field research. Negative soil-related developments in these ‘new’ systems have already been identified in Queensland (Bell 2005). Brown (2004) formulated these phenomena as “For every action on a complex, interactive, dynamic system, there are unintended and unexpected consequences. In general, the unintended consequences are recognised later than those that are intended”.

Current practices continue with the use of harsh chemicals and ignore the delicate balance of humus, microbes, trace minerals and nutrients in the soil. Such management has resulted in marked losses in soil organic carbon (including humus) and greatly reduced diversity and abundance of microbes (algae, bacteria, fungi, nematodes, protozoa) and larger organisms (*e.g*. mites, ants, beetles, worms) in the soil foodweb (see *e.g*. Ingham 2006). This exposes roots to harsh conditions, greatly diminishing the capacity of the soil to feed plants, as well as making roots more sensitive to saline and acid condition and the whole plant susceptible to pests and diseases, and requiring plants to be spoon-fed with fertilisers and protected by chemicals (Anderson 2000). Disruption of soil biological and chemical processes usually leads to physical problems, such as reduced infiltration, compaction and erosion. As a result, conventional farming is now searching for answers to increasing soil organic matter and microbial biomass (Bell 2005, Fisher 2005, Kirkby *et al.* 2006).

Ecosystem

A sustainable farming system is a complex ecosystem with non-linear dynamics that can exist in alternate stable states, each state having it’s own threshold for change from one state to another. When a critical threshold is breached, recovery to a sustainable system will become difficult or impossible. For unstable farming systems to again become sustainable, we have to understand ecosystems before we can take the right remedial steps.

Sustainable ecosystems are resilient, having the capacity to absorb disturbance and re-organise over a wide range of conditions before ever reaching a critical threshold. They are characterized by many interactive components within and between scales. Adaptability and transformability are two other characteristics of how ecosystems respond to change. Adaptability is the capacity of ‘actors’ in the system to manage system resilience, while transformability is the capacity to become a fundamentally different system when the existing system becomes unsustainable (Resilience Alliance 2006).

The underlying strategies for moving towards sustainable farming systems are conservation of soil, water and energy resources to maximise food production. This goes back to the functioning of ecosystems, the dynamics of interactions between a community and its non-living environment. Agroecology is an approach in agricultural development which draws on modern ecological knowledge and methods. It is defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems (Gliessman, 2000).

Understanding the functioning of ecosystems requires a ‘big picture’ holistic approach. The knowledge of different groups in the living world and how they interact with other groups is here more important than in-depth knowledge of individual species. Studying the latter, however, and single issues in general, seems to be more popular and advanced. Unfortunately, we can’t understand a system by combining available knowledge of component single issues. That is, the holistic ‘whole’ is not the sum of reductionist ‘detail’. This also needs to be recognised in simulation modelling of systems.

Symbiosis – the balanced, mutual interdependence of different species – is a protective mechanism in nature, which develops in response to compatible needs. Self-organisation keeps natural biological systems in balance. Interactions between organisms are powerful evolutionary forces. Increased complexity and diversity of species and interactions within the soil foodweb promote balance and higher plant productivity. The whole should be considered as an integrated system being resistant and resilient to change through an abundant diversity of organisms.

Plants depend on beneficial soil organisms to protect them from pathogens, to help them obtain nutrients from the soil, and to break down toxic compounds that could inhibit growth. Soil organisms create a living, dynamic system that needs to be understood and managed properly for best plant growth. If the balance of micro-organisms is wrong, fertilisers and pesticides can’t help recover plant vigour. Understanding soil health requires knowing which organisms occur, which ones are working, how many are present and whether they are the right kinds for the desired plants (Ingham 2006).

Soil health thus requires improvement of biodiversity in paddocks and catchments to enhance natural predation in a functional soil foodweb (FAO 2006). This can be achieved by doubling soil organic carbon (the foundation for a living soil), minimising use of chemicals, and the establishment of shelterbelts for improvement of soil surface microclimate and provision of a ‘home’ for an important part of the soil foodweb. Paddock soil then becomes resistant to change and, being resilient, is able to recover from disturbances caused by extremes in weather or management. Such soils will remain more productive with climate change as living soil organisms can adapt. It will also help slow climate change by sequestering carbon (Leu 2006a, Carbon Coalition 2006).

Further ecosystems improvement may be achieved by managing natural energies with permaculture (PRI 2006), Yeomans’ Keyline Designs (Yeomans 2006) or Natural Sequence Farming (NSF 2006) to fit paddocks into a sustainable landscape. Natural Sequence Farming is a rural landscape management technique aimed at restoring natural water cycles that allow the land to flourish and be less sensitive to drought conditions (Newell 2006). This goes back to the natural balance of water cycles as pioneered by Peter Andrews in conjunction with biological farming principles (Andrews 2006, NSF 2006).

Another strategy in the move towards sustainability and ecosystem protection is reducing the vulnerability of farming to the economic impact of diminishing oil availability (Peak Oil 2006) by decreasing its reliance on petrochemical products.

Science

Current specialisation in agricultural science has resulted in research within very narrow boundaries. This has induced linear, mechanistic thinking, which doesn’t allow room for synergies, and results in confusion between cause and effect. Soils, for example, have become partitioned into separate isolated fields of chemistry, physics and biology, with further specialisation within each. Unfortunately, soil degradation and the issue of how to restore healthy soils cannot be solved with many individual research projects conducted by various specialists. It needs a big-picture approach. In nature everything is linked with everything else. These circular, web-of-life phenomena have to guide our applied field research.

Much current ‘sustainability’ research is fiddling at the margins of entrenched methods, working on symptoms rather than the primary cause of problems – as evidenced by appearance of new problems after implementing ‘solutions. It is not simply a matter of doing better what we do. ‘Best practice’ locks us in status quo which is still not good enough!

If agricultural research is to deliver anything approaching sustainability, therefore, we need to change the science paradigm (Jackson 1985). Or as Dr Albert Einstein said: *“No problem will be solved with the same level of thinking that created it in the first place”*. Over generations research has become increasingly “reductionist”, that is, reducing and outlining systematically the area of interest to be studied and the disciplines to be used. While this approach of fragmentation has delivered a lot of knowledge about the workings of particular crops, pastures, livestock, insect pests, chemicals, etc, focussing too intensely on closed systems with narrow boundaries – on single, isolated components of the bigger “real-world” system – means we are blind to larger cycles and patterns within which component parts exist (Stapper 2002). In this way, the biological sciences themselves fragment our understanding by creating false divisions that break the cycle of life.

New problems keep emerging as each of them are dealt with as single issues, resulting in partial solutions that don’t necessarily solve the problem, for example, acidity (with lime) and salinity (with lowering ground water). Partial solutions tend to equate a single solution with the cause of the problem but lime and ground water, for example, are not always directly related with acidity (Anderson 2000) and dryland salinity (Jones 2001, 2006), respectively. Soil management related causes for dryland salinity have been derived from practical experiences in, for example, New South Wales (Wagner 2005), Victoria (Nathan 1999) and Western Australia (Paulin 2002).

Experimental results dealing with isolated individual components are thus difficult to apply to paddocks, which are complex systems in time and space. What does an ‘average’ mean in a paddock? Other management factors are likely to be working against the application of individual research results, thereby inhibiting change. Hence, problems continue to emerge in agricultural production systems. Science is now proposing genetic engineering as ‘the’ solution for many of these problems – risking yet another oversimplification in our fragmented agricultural science (Stapper 2002), a ‘techno-fix’ with more band-aids over the real cause of our problems – degrading soils.

The standard multi-factorial research methodology seems ill-suited to studying complex biological systems where everything is linked with everything else. To obtain functional outcomes, no factors may be considered ‘constant’ in trials while varying a few ‘important’ factors to quantify their impact. Also the boundary conditions of research objects chosen by specialists (*e.g.* pots and small plots in a growth chamber, green house or research station) are often not appropriately representative of real ecosystems (especially microclimate) and generate results not transferable to the farming-system level. Comparative analysis is needed on a commercial production scale. Questions arising from such studies then need answers through reductionist science.

New methodologies and directions of research are required in the search for resilience, to achieve reproducible and predictable outcomes in farming systems across agroecological zones. Such research needs to be planned, executed and analysed by a transdisciplinary team working across ecosystems at representative scales, that is, in agroecology (Gliessman 2000, Altieri 2006). This is to allow observation and measurement of expressions of the multitude of interacting components within and between different scales of the farming system. Plant health (Anderson 2000) and animal health (Voison 1958), for example, are dependent on availability in the right balance of minerals, but this is still regarded as ‘alternative’ thinking.

To reach sustainability in agriculture we have to look at the whole system and develop holistic tools within agricultural science that bring together, from across disciplines, the knowledge obtained through analytic reductionism, without getting lost in small component details of 'what single factor? – the how? and why?' Such tools are unlikely to be quantitative, hard systems, as dynamic interactions by soil organisms are too complex and too affected by small spatial and temporal changes in management and climate. Therefore, a soft systems approach is required, synthesising knowledge into management guidelines for sustainable land use combined with careful monitoring of status.

Australia's public R&D in this direction is minimal, and seems to be one of the lowest of OECD countries as was evident at the recent International Federation of Organic Agriculture Movements Congress in Adelaide (ISOFAR 2005). Nevertheless, we must search for productive agricultural systems with reduced usage of petrochemicals and energy, and not rely on 'Techno-Fantasy' to help us out. As we face a future without cheap oil, science must play a role in dealing with the profound socioeconomic change now gathering momentum around us (Heij 2006).

Management

As managers using the soils, what do we look at, what do we (want to) see? After decades of regular use of single-super phosphate some farmers and graziers stopped using it when they became aware of the detrimental impact it had on soils and trees, caused by the acidic nature of the fertiliser; use of muriate of potash (potassium chloride) has similar impact and also needs to be avoided.

We can learn to use the power of nature rather than fighting it with synthetic chemicals and unproven new technologies in a war we can't win. Organic Farming is surging and Biological Agriculture (Anderson 2000, Zimmer 2006) is emerging as a sophisticated farming system in transition between current and organic. Both benefit from reintroduction and enhancement of humic and soil biological activity, components already fundamental in Biodynamic Farming (ATTRA 2006). In contrast to the Organic standard, Biological farming allows for minimal use of the most microbe-friendly fertilisers and herbicides with humic additives and molasses or sugar to enhance effectiveness and reduce damage to microbes. This requires ever smaller quantities as the system is balancing and moving towards Organic, a process that occurs much more quickly when actively managed with biological inputs.

Management aims to balance chemistry, physics and biology in the soil aided by improved organic carbon content, appropriate mineral balance and a diverse and abundant soil life. Thus stabilising our fragile soils and creating a sponge that stores and makes available required plant foods and facilitates prolific root growth. Soil biology helps with building and maintaining soil structure to secure aeration and prevent compaction. A balanced biological soil will have the maximum levels of available minerals coinciding with maximum demand by plants.

The farming system is intended to enhance biological activity in soil and on foliage, enabling a balanced supply of required minerals for effective plant growth, providing energy to plants and grazing animals. Soils are actively re-mineralised, inoculated with soil microbes and supplied with food for microbes, all required in order to achieve and maintain an energetic balance.

Cover – With cropping and in orchards, the soil should be covered most of the time by green plants or at least stubble to protect from high temperature and water loss. A litter layer as cover will be a continuous source of carbon for soil organisms and also provide temperature insulation and water retention. Green manuring provides opportunities to convert rainfall into soil fertility.

Weeds – Weed growth is minimised with soil minerals being in balance and with lowest levels of freely available nitrogen. Mineral availability provides conditions that produce certain weeds, which can be used as an indicator of mineral deficiencies (Walters 1999). The weed spectrum changes immediately when soils are balanced using appropriate materials. For example, from stinging nettle domination (sign of calcium unavailability) one year to no nettles and some shepherd’s purse as the main weed the next. This is the ecological concept of succession, with different suites of species supported on the same area of land as soil conditions change over time (see *e.g*. Ingham 2006).

Insects and diseases – Biological farming is non-pesticidal management (NPM) and uses natural techniques to prevent insect and disease damage. This is a major step ahead of integrated pest management (IPM) which aims to minimise pesticide use to prevent or delay resistance. Preventative measures are important before and after sowing but start with a healthy soil where biological activity builds internal plant resistance to diseases and insects (Callaghan 1975, Anderson 2000, Ingham 2006). Depending on the risks and size of operation, the management options are crop sequence, inter-cropping, trap crops/weeds, seed and foliage inoculation, neem and other natural repellents. Plant sap sugar content can be used as a guideline for protective sprays (see ‘Tools’ below).

Variety choice – Most current varieties have been selected to produce well in high-input management systems and require such treatment to perform as expected. New varieties need to be developed under organic-biological conditions to optimise production with low input on healthy soils. The first step is to evaluate ‘old’ varieties that were selected before nitrogen availability became a priority for plants. A variety will improve with successive seasons if the seed is retained and used again as it keeps adjusting to local soil biology.

Rhizosphere – The rhizosphere is the area of intense biological and chemical activity close to the root inhabited by soil microbes feeding off exudates from the root, thus facilitating nutrient supply to the root and protecting it from pathogens. Fertiliser applied with the seed at sowing decreases root growth, root branching and the number of root hairs. Applying microbes, humic substances and food for microbes with the seed (*ie* inoculation) generally results in a vigorous seedling with many roots, a thick rhizosphere, prolific branching and many root hairs, without the need for conventional seed-dressing. Such annual plants when pulled out of the ground at flowering still show a vigorous rhizosphere. Microbes keep colonising the roots as they grow, thus providing a continuation of that good rhizosphere. It has been demonstrated that an active rhizosphere can be created in degraded, acid or saline soils, with that neutral zone around the root allowing vigorous plant growth. Such a ‘carbon pump’ into the soil will improve that soil and the increasingly active soil biology will segregate negative compounds. Carbon may thus help stop dryland salinity (Jones 2006).

Inputs – The most important inputs are foods for the soil microbes, with the most effective one being carbon exudates from roots of growing plants. Maximising the time of active plant growth is therefore most important. Rotational, cell, or planned grazing (large number, small area, short time), for example, facilitates root growth and delivers more carbon to the soil than set-stock grazing. Another example is pasture-cropping where winter crops are sown into summer-active perennial pasture (Bruce 2005, Jones 2006, Seis 2006).

Residual stubble and roots are also important sources of carbon. Stubble, however, needs to be broken down to be available for soil organisms. To facilitate this if breakdown is slow, a stubble digest, containing cellulose-digesting fungi and some urea to lower the C:N ratio, can be sprayed onto slashed, spread and rolled stubble with or without incorporation. Such management decisions depend on the amount and kind of stubble, paddock history and soil biological activity – *i.e*. whether or not such bugs are already present.

Carbon can be applied as molasses, sugar, humates or brown coal (in order of decreasing availability). Humic substances, such as humus, humate, humic acid, fulvic acid and humin, are important forms of carbon for plants, playing a vital role in soil fertility and plant nutrition. Plants grown on soils which contain adequate humin, humic acid and fulvic acid are healthier and less subject to stress, and the nutritional quality of harvested foods and feeds are said to be superior (Pettit 2006).

Soil microbes, food for microbes and minerals can be applied as required by spreading, down the tube, or as foliar or soil spray with possible micronised minerals. To provide an optimum start of plant growth through the creation of a vigorous rhizosphere, the standard practice is to inoculate seed with microbes. This can be done by tickling some 10 l/ha of microbe containing liquid on the seed at transfer from silo (needing less then 20 minutes to dry before sowing), or dripping a liquid containing microbes and minerals in the soil on the seed while sowing.

Microbes can be applied as compost tea (Ingham 2006) or as a commercial mix (*e.g*. the internationally well known 'EM' (Effective Microbes) or '4/20'). These mixes may contain free-living nitrogen fixers (*e.g*. Azotobacter), bacteria that establish in the litter layer and can provide 20 to 70 kg N per ha per year depending on moisture and carbon availability. Phosphorus solubilisers are another bacterial group that may be included to make available the P applied in the past and locked up in soil clays. The importance of Biodynamic preparations (*e.g*. 500, 501, Cow Pat Pit) and application (time and method) does not just rely on bacterial content, but also on their stimulation of the activity of other soil bacteria and fungi.

Other inputs can be organic in nature, such as seaweed, fish protein, guano, soft rock phosphate, lime and rock dust, or in biological farming, inorganic microbe-friendly fertilisers in small amounts, such as sulphate of ammonia, calcium nitrate or mono-ammonium phosphate (MAP). Lime is regularly applied (0.4 to 1 t per ha) for calcium to be available – a very important mineral requiring fungi for availability to roots (*e.g*. Ingham 2006).

Compost is an important and effective method for delivering carbon, organic compounds, minerals and microbes to the field as a readily available organic fertiliser. The best compost contains up to 90% of the carbon in microbial biomass, that is, bacteria, fungi, protozoa and nematodes (Ingham 2006). Compost tea can be extracted from good compost and sprayed in orchards and on broadacre crops and pasture. Vermicomposting is the process by which worms are used to convert organic materials into a highly effective humus-like material known as 'vermicast' and its effluent 'vermiculture'.

Trials – It is good to do trials on your own property to find out how things work. It is best to leave test strips on the paddocks, including a nil strip to see what would have happened if you hadn't done something. It is important to keep good records and markers in the field to be able to keep track of a treatment in one season and over subsequent years. Current yield monitors are providing grain growers with a good tool to quantify differences.

Monitoring – "*you can't manage what you don't measure*" – Monitoring of soil and plants is important to be able to see improvements when changing management, and to allow early detection of required management. It is important to monitor different paddocks and use these records to try to quantify different solutions to a problem. Monitoring is a great learning tool, especially when comparing a similar crop across different paddocks or on a given paddock over seasons. Keeping good records facilitates discussion with other landholders and advisors. For example, a Soil Health Card with recording instructions was developed by a Landcare group in the Northern Rivers region of NSW (NR 2006).

A home-made penetrometer (see tools) is the great tool to monitor progress in and between paddocks as an improving soil biology alleviates soil compaction, making soils more aerated and easier to penetrate by roots.

Pulling plants out of the soil is a test to help assess microbial activity. Naked roots usually mean a dense soil with little microbial activity. A thick soil layer stuck to roots (*i.e.* the rhizosphere) with prolific branching of the roots is an indication of a well aerated soil with active soil biology. Plants will have more solid stems, especially perennials like lucerne. Keep records of weeds as indicators of movements in soil mineral availabilities.

Smell the soils and discover the sweet smell of a healthy soil. Lab soil tests are the classic tool to get some chemistry numbers on what's in the soil. However, it is important to also assess the biological availability of essential elements and their balance, as provided by special labs. Deficiencies are relative, as productivity can be adversely affected by excess. Soil minerals can work together or be antagonistic to each other. An excess of one will create a deficiency of another.

Tools – Descriptions of home-made equipment are given with the Soil Health Card (NR 2006). A wire quadrat is used for soil cover estimates or weed/plant population densities, a penetrometer (from fence wire) to monitor hardness of soil, and an infiltrometer tube to measure rate of water infiltration.

Plant sap will reflect improvement in mineral availability and sugar content, and can be monitored in the field with a refractometer giving a brix reading, which needs to be above a crop-specific minimum to keep insects and diseases away (Anderson 2000). Increasing fussiness of the measurement line indicates increased presence of minerals (*e.g*. Calcium).

A pH-meter can provide you with information as to whether plant sap is at the healthy neutral level, meaning the soil is in balance energetically. In Biological Agriculture a pH-meter should also be used to make sure any herbicides are applied with a pH as low as 4, and with fulvic acid as additive, to greatly increase effectiveness.

Outcomes

Farms that have achieved healthy soils look and smell good, with dung beetles present in pastures and no slugs or snails in crops. Plants growing on such farms have less disease and insect damage, less frost damage (high sugar content or 'brix' in plant sap), have great root systems, and taste better. For example, canola and lucerne having no to minimal insect damage without pesticides after commencement of biological farming. Animals show the most extraordinary health (*e.g*. lack of foot rot, bloat, pink eye, mastitis), fertility (*e.g*. +25% lambing), and longevity. They need less fodder and graze for shorter periods compared with available conventional feed systems. Think of what could happen to humans if we ate such food!

Biological farming can reduce fertiliser use by up to 50% and eliminate fungicides and insecticides within three years of commencing. Such personal statements about achieved outcomes are available in company newsletters and articles in rural magazines but independent quantification is rare (Stapper 2004). Most methods haven't been proven scientifically, failures are experienced if methods or conditions are not right, and are therefore rubbished by many.

Improved soil biological activity becomes visible through the presence of earthworms and many 'creepy crawlers'. Common soil problems have been alleviated such as acidity, salinity, compaction, water logging and wind erosion (no dust behind sheep). Water-holding capacity has been improved, which shows, for example, on irrigated farms through a 2-3 day extension between irrigations. The retention of water also seems greatly improved as topsoil remains moist longer. Improved soil organic carbon manifests itself through many factors, but the overall benefit can be great. For example, one study in NSW quantified the value of soil organic carbon as $116 per one percent increase, resulting from better water holding capacity and nitrogen availability (Ringrose-Voase *et al.* 1997).

As in current systems, not all inputs are always effective. Success in biological systems depends on many factors working together. Soil organic carbon formation from roots and stubble, for example, requires not only the presence of microbes but also availability of important nutrients as the C:N:P:S ratio of organic carbon is similar across the world (Kirkby *et al*. 2006). Something can fail if a catalyst is missing. Nevertheless, when everything connects, we can get responses beyond expectation as synergies ('1+1=3') start to occur. We are, however, on the right track. An organic farmer from the UK, a Nuffield Scholar having visited the USA regularly, stated in February 2006: "*I have seen some truly exceptional farmers who are light years ahead of anything I saw in America, particularly where it really counts, in the practical application and making it work on farm.*"

Lal (2006) found that enhancing soil quality and agronomic productivity per unit area through improvement in the soil organic carbon pool will increase food production in developing countries, with numerous ancillary benefits. Adoption of recommended management practices on agricultural lands and degraded soils would improve soil quality including water holding capacity, cation exchange capacity, soil aggregation, and susceptibility to crusting and erosion.

Many have studied the impacts of farming methods on environment and food production. For example, studies have shown reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilised soils (Kramer *et al.* 2006). Impacts of herbicides on rhizobium survival and recovery with reductions of up to 60% in nitrogen fixation have been reported by Drew *et al.* (2006). Organic agriculture often is a proven good producer of food with yields comparable to those of conventional agriculture both in poor (Parrott and Marsden 2002) and rich (Maeder *et al*. 2002) countries. Gala (2005) and Leu (2006b) provide detailed accounts of studies from many countries.

With acquired knowledge, NPM is becoming successful in poor and rich countries in a move away from petrochemicals. India, for example, with three-quarters of farmers on less than 1.4 ha, is increasingly going back to traditional knowledge, which, combined with current knowledge and logistics, is leading to productive, profitable systems (Rupela *et al.* 2006, CSA 2006)

Organic technologies have been developed over about 6000 years to feed mankind while conserving soil, water, energy and biological resources. We are now able to increase yields for these low-input systems by using our breeding knowledge and methods to select higher yielding varieties adapted to local conditions (*e.g*. to improve harvest index). Among the benefits of organic technologies are higher soil organic matter and nitrogen, lower fossil fuel energy inputs, yields similar to those of conventional systems, and conservation of soil moisture and water resources – the latter being especially advantageous under drought conditions (Pimentel *et al*. 2005).

Cuba is the first country to develop agroecological systems nationwide – as a result of the disintegration and collapse of the Socialist Bloc and tightening of the US trade embargo which prevented access to petrochemicals. Cuba successfully turned to self-reliance, organic farming, animal traction, biofertilisers and biological pest-control, while retaining agricultural productivity – a remarkable paradigm shift (Funes *et al*. 2002).

The road to sustainability

While ‘sustainable agriculture’ has been defined in many ways, it is fundamentally a process of social learning, not led by a science that overemphasises production and neglects maintenance functions within agroecosystems. Hill (1998) sees this blind spot as one of a number of indicators of our undeveloped and distressed psychosocial state. Habits, perception and assumptions determine what we see and want to see, and correlation is not cause. This realisation is another aspect of the change that will be required in our paradigm – the way we learned to see the world.

How do we find the road to a sustainable agriculture producing healthy food in a healthy landscape? How do we turn our ‘Clean and Green’ image into reality? Minerals and microbes are the key, in both soil and human health. Over the past 60 years, mineral density of foods has declined to less than half of former levels (Bergner 1997, McCance and Widdowson 2000). We need to increase it again through improved production systems, and keep it available with proper food processing, so that good nutrition returns to the way our foods are grown, processed and prepared. Real medicine must start with the patient’s diet and, ultimately, the nutrition on the farm (Anderson 2000, 2004). Worthington (2001) and the Soil Association (2002) found genuine differences in nutrient content of organic and conventional crops – improvements which could be even greater if all organic crops are actively managed with microbes and minerals. Farmers and graziers need to be paid for such quality.

Active management of the soil foodweb, remineralisation, and substantial increase of soil organic carbon are essential to reaching ecologically sustainable production systems and a (less-un)sustainable agriculture. Such a system produces healthy food with good taste and structure (*i.e.* availability calcium and silica), and extended shelf-life.

Trees are important as shelterbelts in a dry, wind-swept continent. There are examples in many districts where farmers have converted a proportion (say 10%) of their property to trees and wetlands (often from say 0.5%), resulting in improved productivity through improved water use efficiency and decreased sensitivity to droughts. This will especially be the case when appropriately combined with Natural Sequence Farming which rehydrates the landscape and makes soils healthy when following Peter Andrews' principles that include biological farming (Andrews 2006). Healthy, living soils will be able to adapt to a changing climate.

Organic-biological farming methods seem promising on a landscape and catchment scale, as they result, through minimizing the use of synthetic chemicals, in farming systems that stimulate biodiversity, stabilise the soil, and balance the hydrology, thereby reducing off-farm impacts. It is important to mix and match such systems with landscape changing initiatives such as permaculture (PRI 2006), Keyline Design (Yeomans 2006) and Natural Sequence Farming (Andrews 2006, Newell 2006, NSF 2006) – thus increasing the knowledge intensity in farming.

In most districts today, there are properties applying sustainable practices as outlined above. These practices have been achieved with persistence by the manager – through trial and error, under financial pressure, and on fragile soils in our highly variable climate. It is now the task of science, using participatory research, to connect up these 'dots' in the landscape using appropriate concepts and principles. A typical agricultural manager is both time poor and cash poor – thereby, of necessity, readily following advise from (trusted) outsiders. Action research is needed to develop indicators that conceptualise farmer knowledge of natural resource management. This, in turn, will feed the required information-exchange networks, allowing knowledge to be transferred in time and space to achieve and maintain soil health, optimise production and minimise risk to achieving profitable farms in sustainable rural communities.

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(*NB. All internet references are to their July 2006 content*)

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