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Agroforestry and Conservation Agriculture: Complementary practices for sustainable development

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Introduction

If the world seems to be facing some daunting problems on the financial and environmental fronts, then the developing world is battling for the very existence of many of its people. The first UN Millennium Development Goal pledged to eradicate extreme hunger and halve the proportion of people suffering from chronic hunger, all by 2015. We are nowhere near to achieving this goal, and in fact in sub-Saharan Africa (SSA) the situation is getting worse. The world's population is now up to 6.75 billion and rising (see http://opr.princeton.edu/popclock/ for a current estimate) and some 30% of sub-Sahara's 770 million population are chronically hungry today. On top of an already dire situation we can, as we allocate greater resources to biofuel production, see the impact of sharply escalating food prices (especially for the world's staples of rice, wheat and maize). The result of this is that there is today an urgent need to produce sustainably greater harvests from the world's agriculture. The judicious combination of the environmentally friendly practices of conservation agriculture (CA) and agroforestry (AF) will be solid building blocks on the road to achieving this goal.

The impact of many current agricultural practices is having a deplorable effect on the world's soils, water resources and rural environments. Natural levels of annual soil loss are very small (Morgan, 2005) in the region of 0.0045 t ha^{-1} for areas of moderate relief and only rising to 0.45 tha^{-1} on steep slopes. This can be compared with rates of 45-450 t ha^{-1} for agricultural lands. Of course it is not just the quantity of soil that is being lost as a result of unsustainable agricultural practices, soil quality suffers as soil fertility is associated with the preferentially eroded smaller soil particles. The reduction in tillage and the addition of organic matter (OM) and N by cover crop legumes lead to a steady increase in soil organic carbon (SOC) with corresponding improvements in levels of N, P, K, Ca, Mg, greater pH and cation exchange capacity (Benites, 2008). The erosive processes of water and wind remove soil fertility with the first soil to be lost. This will quickly give rise to a loss of soil productive capacity resulting in lower yields or higher fertilizer costs.

It is not just loss of soil fertility that results from the soil degradation as a consequence of unsuitable farming practices: water resources, biodiversity and ecosystems are also affected negatively. Soils protected by CA or AF have improved water holding capacities. The enhanced network of macropores (produced as a result

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of root exploration and soil fauna, principally earthworms) facilitates the infiltration of rain water into the soil profile, and hence improves aquifer recharge (Friedrich, 2005). The increased soil organic matter (SOM) levels improve the availability of water accessible to plants (1% of OM in the soil profile can store 150 m^3 water ha^{-1}). Not tilling the soil will reduce soil moisture evaporation and, overall, crop water requirements can be reduced by up to 30% with no till.

Biodiversity is especially improved following the adoption of CA and AF practices. Increased SOM will support the full range of bacteria, fungi, protozoa, beneficial nematodes, worms and arthropods which become the barometer of a productive, healthy soil (Blank, 2008). Blank affirms that: 'the soil foodweb greatly improves nutrient retention and cycling, aggregate structures, increased soil O_2, water dynamics and pathogen suppression.' It follows that improvements in soil quality and health as result of judicious CA and AF practices will have a marked beneficial impact on ecosystems as biodiversity is enhanced and water quality is improved. In addition the quantitative benefits of the reduced leaching of soil nutrients and agricultural chemicals, together with reduced soil erosion lead to real improvements in environmental water quality.

After much procrastination, the world is becoming increasingly, and more painfully, aware of the imminence of the negative impacts of climate change. Climate change is already occurring and constitutes a major factor to consider in future food production and land management. Some regions may benefit from changes in temperature and rainfall patterns whereas in others the changes will be disastrous. One of the major concerns of global climate change is the melting of the polar ice pack. Data show this is happening much faster than anticipated. The result will be an increase in the level of the oceans affecting much of the agricultural land in coastal areas. Another concern is the melting of the Earth's glaciers that supply fresh water for agriculture and human needs; the Himalayan glaciers are an example of this. These are the major sources of fresh water for the irrigated food bowls of NW India and Pakistan, an area of the world that is dependent on irrigation and would be a desert without it. Other global climate change effects would be temperature changes (up or down), droughts, floods, and more erratic and violent weather (hurricanes, typhoons, etc.) that could seriously affect mankind's ability to produce enough affordable food for the world's population or at least in countries seriously affected by climate change (Sims *et al*., 2009). Action must be taken to reduce the impact of greenhouse gas emissions on climate change. Once the permafrost starts melting, large quantities of methane (with a heating potential 21 times greater than carbon dioxide) will be spewed into the atmosphere with even more serious effects on warming the planet. Policies are needed to reward activities that result in increased carbon sequestration and reduce these emissions. Policies and institutions that would promote the use of environmental and sustainable farming practices like CA and AF are one way to achieve this.

The concept of CA and compatibility with AF

What is CA?

In summary CA can be described (www.fao.org/ag/ca/) as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is characterized by three principles which are linked to each other, namely:

1. Continuous minimum mechanical soil disturbance.
2. Permanent organic soil cover.
3. Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops.

CA as a forest mimic

CA, with its minimal soil disturbance and maintenance of permanent soil cover, tends to mimic natural systems, particularly that of the rainforest. In forest systems, nutrients are recycled via leaf fall and decomposition which requires a rich soil biota. Removal of this cover, resulting in the destruction of the natural channels for water infiltration and gaseous exchange, means that natural sustainable systems would need to be replaced by expensive and damaging tillage for crop production. Permanent soil cover also provides other important benefits to the soil (the control of soil temperature and moisture content are two of them) but above all, cover protects the soil from the degrading effects of wind and water erosion. As has been pointed out, erosion rates under CA, AF and forest systems can be reduced to practically zero.

Compatibility of CA and AF

Agroforestry is, of course a multifaceted concept, but at heart it integrates trees into farmland and rangeland and in so doing diversifies and sustains production for increased benefits for farmers and the environment (Elevitch, 2004).

Table 1 gives an analysis of the compatibility and complementarity of AF and CA system benefits.

Table 1. Benefits, complementarity and compatibility of AF and CA (adapted from Elevitch, 2004)

Concept	Constituents	Potential of AF and CA
Efficiency of natural resource use	Soil nutrients	Trees promote nutrient cycling and N fixation. Compare this benefit with the recycling capacity of rotating main and cover crops with different rooting depths in CA systems. Leguminous cover crops also fix N.
	Solar energy	Multi-storied cropping systems intercept and use sunlight at all levels. Although this is a benefit better illustrated by AF systems, crop associations in CA demonstrate similar efficiency.
	Water	Both AF and CA reduce runoff while increasing water infiltration and holding capacity in the soil.
Favourable environment for sustained production	Shade	AF (and some CA) systems can provide filtered shade which conserves water and reduces evapotranspiration, keeps topsoil cool and helps maintain healthy soil biota activity.
	Wind protection	Tree wind breaks protect crops from wind damage and soils from wind erosion and drying. Wind breaks combined with CA give more complete protection.
	Soil conservation	Undisturbed tree, crop and cover crop roots and mycorrhizal systems reduce nutrient leaching, bind soil and prevent erosion. Tree leaf litter and CA soil cover enhance soil physical, chemical and biological conditions making soils more resilient to erosive forces
	Nutrient cycling	Through nutrient uptake from deep soil layers and N fixing species, trees, bushes and cover crops promote more closed nutrient cycling and more efficient use of nutrients.
	Habitat diversity	Both CA and AF, but more especially in association, provide habitats for diverse biota that help to enhance biodiversity and pest/predator balance in the system.
More profitable systems	Reduced costs	Through nutrient cycling cover crops and trees reduce the need for purchased fertilizers. Fuel and labour costs are reduced in CA systems compared with plough-based agriculture
	Diversified products	Mixed cropping systems typically have more economic products. For example tree fruits and timber in AF, leguminous seeds in CA.
	Continuous flow of products	With multiple cropping in both AF and CA, there can be a more even supply of products throughout the year
	Greater self reliance	AF and CA can reduce the farm family's dependence on purchased products as well as reducing vulnerability to changing market conditions, especially for mono-cropping systems
Environmental improvement	Reduced pressure on natural forests	This is particularly an advantage for AF systems which reduce pressure for forest products.
	Species diversity	Both AF and CA provide enhanced habitat and support for biodiversity for macro and micro fauna
	Resource conservation	AF and CA improve the conservation of soil, nutrients and water in the landscape.
	Carbon sequestration	Trees and, especially soils, store C and so reduce GHG emissions.
	Decreased pollution	Nutrient cycling can reduce the need for inorganic fertilizers and reduced erosion and runoff mean that nutrient loss approaches zero.

Sustainable soil management for production intensification

Rattan Lal has developed ten principles for sustainable soil management[3] which, when examined in turn can show how both CA and AF are inextricably linked to sane and sustainable practices which allow production to be intensified while protecting the environment. The principles distilled by Lal are:

1. **Minimizing soil degradation depends on addressing the human dimensions that drive land misuse**.

While it is true that AF systems incorporate species and techniques that have been used traditionally in smallholder farming systems; sometimes the traditional knowledge of CA has been lost by the imposition of alien cultivation practices (exemplified by the use of the mouldboard plough). CA is not a new paradigm either; it has been in use for many centuries in many parts of the world before the advent of mechanical tillage.

2. **Suffering people pass their suffering to the land**

People suffer for two main reasons, population pressure on existing resources means that there are too many mouths to feed with too little food. And secondly globalization and the aggressive imposition of neo-liberal policies mean that poor people are getting poorer and are therefore unable to compete for food with their diminishing resources. The result is mining of natural resources.

3 If outputs exceed inputs then soils will degrade

The mining of nutrients in many smallholder systems has led to this situation. Soil erosion will also deplete soils and soil nutrients. Farming systems that employ CA and AF actually increase soil organic matter and so enhance soil nutrient status.

4. Marginal soils cultivated with marginal inputs will produce marginal yield and support marginal living

This is, in effect, the farming system used by a depressingly large number of smallholder farm families, especially in SSA.

5. Crops do not differentiate between organic and inorganic inputs

Both AF and CA supply nutrients in both forms. Organic sources in CA and AF are much higher than in conventionally-tilled soils with no AF practices. Also, crops have co-evolved with many micro-organisms that make up healthy soil systems in which these play a range of functions beneficial to crops. These include: nitrogen fixation, nutrient cycling and storage, improving soil porosity, aeration, and available moisture.

6. Mining carbon has the same effect on global warming whether through tillage or burning fossil fuels

Both AF and CA sequester C in soil and biomass. CA farming typically uses half the fossil fuel requirement of plough-based systems.

7. Soils can be a source of C extraction or a sink for C storage

[3] http://www.lesspub.com/cgi-bin/site.pl?332&ceNews_newsID=6259

When used as a C sink (as in AF and CA) soil can store 3 giga[4] tonnes of C per year which translates to a reduction of 50 ppm CO_2 in the atmosphere[5].

8. Genetically modified crops cannot yet extract water and nutrients from a soil that does not contain them

GM crops are not a panacea, they cannot do the impossible. They can only perform well, along with any other crops, where soil and water are managed sustainably as they are in AF and CA systems.

9. Improved soil management is the engine of economic development in rural communities

This is a reasonable, if often sadly neglected, viewpoint. Without the biologically healthy soils produced by CA and AF practices, many rural communities are condemned to grinding poverty without a clear strategy for exiting the vicious cycle.

10. Traditional knowledge and modern innovations go hand in hand

Traditional knowledge has brought us to where we are in terms of stable, sustainable agriculture. But with increased demographic pressure farming practices need to be modified in the light of modern knowledge. Both CA and AF draw deeply on the well of traditional indigenous knowledge. But we have seen that innovations in the field of machinery, IPM and soil management (for example) are necessary to sustain production at levels high enough to stave off mass starvation in the future.

These ten principles are relevant to many aspects of agricultural production under AF and CA. The following sections examine some of them in more detail.

Soil health and productive capacity under CA and AF

Undisturbed soils under AF and CA practices have much lower erosion rates than mechanically tilled soils and this results in an accumulation of SOM, an increase in soil nutrients (especially N) coupled with an increase in CEC, greater crop resistance to pests and diseases; enhanced soil porosity and aeration, water holding capacity and infiltration rates and improved soil structure.

Improved soil health, in terms of a healthier soil biota, results in a healthy soil food web which performs the following vital functions (Ingham, 2004):

- Disease suppression
- Nutrient retention
- Nutrient recycling
- Decomposition of plant residues and plant-toxic compounds
- Well structured and aerated soil

Improved soil health, nutrient status and structure will, almost by definition, result in greater crop production capacity.

The need for a holistic approach to soil management

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[4] $G = 10^9$

[5] 2009 levels of CO_2 are 390 ppm. www.carbonify.com.carbon-dioxide levels.htm

In the case of both AF and CA optimum soil management for sustainable production intensification is achieved by treating a soil as a biological system and by working with nature and rural communities in an all-encompassing way. Concentrating only on the physical or chemical aspects of soil improvement whilst disregarding the social impacts of AF and CA adoption is unlikely to result in successful management and sustained adoption.

Many observers have reflected on the necessary conditions for adoption. For example Rolf Derpsch (Derpsch, 2008) offers his top ten critical factors for no-till adoption:

- **Improve your knowledge about the system**. All aspects of the production system need to be considered in order for the soil to receive the best management: field surfaces need to be level; crops need to be chosen from the points of view of residue production, rooting depth, soil nutrition and weed control; weed control strategies need to be planned; machinery requirements need to be assessed.
- **Analyse the soil**. Without knowledge on the initial condition of the soil (nutrient and pH status, texture and structure; compaction and plough pans) it will not be possible to monitor the improvements achieved under CA.
- **Avoid soils with bad drainage**. No-till, alongside other crop production systems in general, faces problems under these conditions.
- **Level the soil surface**. This is required for good quality direct seeding. Wheel ruts and erosion rills must be smoothed before the planned CA regime. A special form of surface structure – permanent bed systems for row crops, surface irrigation systems or badly drained soils – may be appropriate under some circumstances.
- **Eliminate soil compaction**. This can be produced by wheels and hooves as well as by ploughs, harrows and hoes. The resulting compaction limits root development and reduces crop yields.
- **Produce the greatest amount of mulch cover possible**. This is the source of soil improvement and it must be given priority. The aim should be to produce enough biomass to achieve at least a 100% soil cover throughout the year by choosing appropriate main and cover crops. The higher the biomass added to the system, the faster is the soil improvement.
- **Invest in a no-till planter / seed drill**. This is not the first activity and should only be done when the previous requirements are in place.
- **Start no-till on 10% of your farm**. The change to CA is a complete system shift and the differences (e.g. in weeds, pests and diseases) have to be recognised and managed. This is a steep learning process and should be accomplished carefully and methodically.
- **Use crop rotations and cover crops**. Crop diversity is more important in CA compared with conventional tillage. But diversity must be economically viable.
- **Be prepared to learn continually and keep abreast of innovations**. CA is a continuous learning process. The best source of relevant information is a local successful CA farmer.

The AF case is similar and soil management is a process of 'designing with Nature' (Elevitch, 2004). In the Overstory Book, Elevitch and co-authors discuss the importance of maintaining an integrated systems approach (one which would allow the synergistic addition of CA to AF systems, for example). They also discuss the need of a paradigm shift away from simply exploiting natural resources to actively designing and re-creating resource systems that can mimic nature in form and function (in the same way as CA does). Observation and interaction are more likely to create workable solutions than simple technological advance (Holmgren, 2004) and this agrees closely to Rolf Derpsch's suggested approach discussed above.

A similar holistic approach to sustainable soil management in an African context is recommended in the IIRR-ACT CA manual (IIRR and ACT, 2005).

Rehabilitating degraded lands and water resources through CA and AF
AF is particularly well suited to the rehabilitation of land that has been degraded through wind and water erosion (often as a direct consequence of inappropriate and damaging mechanical tillage practices). AF is frequently judiciously combined with other agronomic practices to enhance the stabilising and rehabilitating impact of trees and shrubs. Some of the most important practices include:

- **Strip cropping, alley cropping and hedgerow intercropping**. Contour hedgerow systems (especially using N-fixing tree species) are widely used to reduce soil erosion in hillside environments. The alleys between the hedgerows are used to grow food crops – preferably with CA techniques to avoid root damage to the tree crop. Hedgerows are pruned to reduce shading and the prunings are used as mulch or fodder, or both. Natural terraces form with time. The high labour input required with tree-based contour systems can be greatly reduced by substituting grass (e.g vetiver).
- **Improved fallow systems**. Seeding land being fallowed between cropping periods with leguminous trees (e.g. *Leucaena*) can rehabilitate soils and prepare them for the next cropping period. This system mimics traditional shifting cultivation practices.
- **Natural vegetative strips**. This is a low cost and very simple way of reducing slope length. Strips are left to re-vegetate naturally (with tree, shrub, grass and other species) along the contour at regular spacings. The Broadbalk hedgerow has been developing from a natural vegetative strip at Rothamsted in the UK since the 1880s[6] and shows that woody species are the natural climax vegetation of undisturbed strips.
- **Buffers**. These include windbreaks and snow fences, riparian buffers, filter strips and watershed protection areas. In AF systems buffers can be multipurpose with soil protection and rehabilitation combined with fruit, nut, timber, and fodder production. As well as improving the habitat for wild life and so encouraging even more biodiversity.
- **Live fences**. Live fences of fast growing, often leguminous, trees (such as *Gliricidia sepium*) can serve not only as fences for livestock and soil erosion control but also seed banks, sources of fodder and fuelwood and for fruit, flower and medicine production. The provision of fodder from tree crops can alleviate the pressure on crop residues so that they can be left as mulch in the CA system.

[6] http://www.forestresearch.gov.uk/fr/infd-5z5gl6

As has been noted, CA is best suited to well managed, productive agricultural areas. But this does not mean that the concepts cannot be used for land rehabilitation, they can. The principle of permanent soil cover is very appropriate to absorbing raindrop and wind energy and so reducing or eliminating wind and water erosion. No-till techniques also retain the soil *in situ* and so prevent particle detachment and erosion. The natural channel system built up by undisturbed soil biota promotes better water infiltration and so reduces runoff and floods.

The strength of CA, however, is that it improves the sustainability of agricultural land use and conserves the available land resources. By increasing soil productive capacity and crop productivity it reduces the pressure on land and this can be very important where unsustainable land use leads to abandonment and expansion into unsuitable areas which should be protected.

CA and AF for climate change mitigation and adaptation

The effects of climate change are already being felt. Desertification is on the increase in SSA as, according to the Intergovernmental Panel on Climate Change, the African continent gets set to bear the brunt of global warming (www.ipc.ch). CA and AF can contribute to the solution to the problem in two ways: adaptation and mitigation. They can improve agricultural system **adaptation** to the impact of change by improving their resilience through providing better soil structure and infiltration rates which will reduce the danger of flooding and consequent soil erosion resulting from extreme weather events. Increased SOM will also improve soil water holding capacity which will, in some cases, allow a crop to reach maturity in extreme drought situations where conventionally tilled soils will dry out completely.

The soil is a major reservoir of the earth's carbon (El-Swaify, 1999) containing >50% of the C pool.

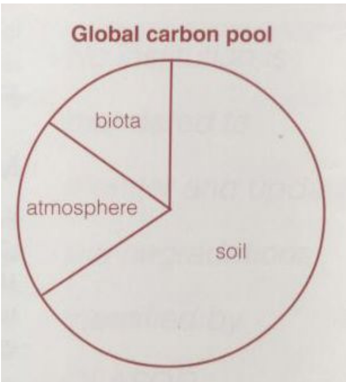

Figure 1. The global carbon pool
Source: El-Swaify p18.

Although the soil is the principle C sink, land plants (and especially forests) are a further major reservoir for C. Increasing forestation, rather than increasing deforestation, which is the current trend, sequesters C and reduces GHG emissions.

Carbon sequestration in CA and AF systems have the potential to contribute to **mitigating** the impact of climate change as greenhouse gas (GHG) release is reduced and the increase in global warming could be slowed[7]. With increased C sequestration (in SOM and biomass) under CA and AF, carbon can be stored for long periods, if not permanently. But there are other ways in which GHG emissions can be reduced:

[7] There is abundant evidence to suggest that it may be too late for mitigation, but we cannot abandon attempts unless we have a better option. We don't (Monbiot, 2009). See also: http://www.monbiot.com/archives/2009/03/17/a-self-fulfilling-prophecy/:.

- Soil erosion releases vast amounts of CO_2 into the atmosphere through organic matter oxidation, contributing to the greenhouse effect and global warming. Lal (1995) estimates that soil erosion releases 1.14×10^9 tonnes of C annually in this way. Soil erosion is reduced to close to zero in CA and many AF systems.
- No-tillage is an appropriate technology to achieve more efficient energy use in agriculture. In NT, crops are planted in just one pass of the tractor, animal powered seeder/planter or person equipped with a jab-planter. Data from South Asia, where wheat follows a transplanted rice crop, show that farmers save up to \$US55 ha^{-1} in diesel costs or 50-60 litres ha^{-1} less diesel for land preparation (Hobbs and Gupta, 2003).

In summary it can be seen that both CA and AF aim to improve soil health, biodiversity and ecosystem services, and increase land productive capacity and enterprise diversification to provide sustainable livelihoods for farmers, especially smallholder farmers.

CA and AF as engines for sustainable production intensification

Farm power shortages drive the poverty spiral

As an illustration of the importance of farm power to smallholder production systems we give a description of the situation in SSA (Kienzle *et al.*, 2009). The inferences drawn are, of course, valid across many developing country regions.

Farm power, which includes the availability of human labour, work animals, engine power, tools and equipment to carry out work, is a crucial input in the agricultural production process. In SSA, the availability of farm power is often a limiting factor that hinders the productivity of the farm. Many households respond to farm power shortages by scaling down their activities, reducing the area under cultivation and growing a limited range of less labour-intensive crops (Sims and Kienzle, 2006). In so doing food security decreases and the household becomes increasingly vulnerable to external shocks. Today in SSA, farm power availability, that is to say the capacity to cultivate the land by whatever means, is a greater constraint to production than access to land.

Improved access to education and persistent urban migration are drawing children and young adults away from farming. The human workforce is also severely hit by HIV/AIDS and malaria, which reduces the number of healthy people available for farm work. This downward poverty spiral increases the vulnerability of fragile households.

The stock of draught animals has been severely restricted by diseases (especially trypanasomiasis and East Coast fever) in some regions. From the 1980s to 1990s, government tractor-hire services were closed and support for private-sector tractor purchases and hire services were gradually abolished (Bishop-Sambrook, 2005).

All these factors that reduce the availability of farm power and so compromise the ability to cultivate sufficient land have long been recognized as source of poverty in the region and two strategies can be proposed to counter the challenge:

- Making existing tasks easier and increasing the productivity of existing labour and draught power;
- Changing farming practices to methods that use less farm power.

Conservation Agriculture is a potential solution to save energy and labour as well as reduce drudgery in both these scenarios. CA overcomes the critical labour peaks of land preparation and weeding by planting directly into mulch or cover crops, with weed control being achieved by soil cover as well as by hand tools and herbicides.

AF systems are not necessarily labour saving but they certainly have the potential to be highly complementary to traditional livelihoods strategies with which they are culturally compatible (Elevitch, 2004). They are locally based, incorporating species and techniques that have been used traditionally in the tropics and sub-tropics for many generations. They are adaptable to changing farm-family, climatic and economic circumstances. And they are acceptable, by combining production with conservation the AF approach can increase the adoption of sustainable practices.

CA reduces energy and farm power needs as well as production input needs

Modern agriculture has prospered but at the cost of becoming dependent on cheap fossil fuels. Fossil fuels are used to power mechanized traction for tillage, cultivation, spraying and harvest, but also for pumping irrigation water, powering dryers and transport of agricultural products and inputs. Fossil fuel energy is also used for powering the Haber-Bosch conversion of nitrogen into urea, a major source of nitrogen fertilizer, the most important nutrient limiting crop yield. The world is very close to "peak oil" (the maximum rate of global fossil fuel extraction) and may have already passed it. Once "peak oil" is reached, available oil declines and the days of cheap fossil fuel will be gone as extraction will fall short of demand. At the same time extraction costs increase as the process becomes more difficult and prices rise both for oil and also the agricultural production that uses it. The rapid spike in fossil fuel prices in the past year is an example of this impact and partly explains the increase in food prices. This will happen well into the future and will require agriculture to use this natural resource more efficiently and ultimately to identify alternative energy sources.

One very promising AF practice which reduces the need for N fertilizers is the employment of the leguminous tree *Acacia albida*[8] in association with other crops. The acacia fixes atmospheric N which is then applied to the soil as leaf litter. As the trees lose their leaves in the rainy season, they do not shade the crop or compete for water. In this way they can replace the need for N fertilizers on the main agricultural crop.

No-till production is an appropriate technology to achieve more efficient energy use in agriculture. In NT, crops are planted in just one pass of the tractor, animal powered seeder/planter or person equipped with a jab-planter. Energy savings data from S. E. Asia have already been mentioned (Hobbs and Gupta, 2003). This is an extreme case because of the difficulty, in traditional tillage systems, of obtaining a fine seedbed on soils that has been puddled for rice (ploughed when saturated). It requires multiple passes of the local 9-tined cultivator or disc harrow to get a fine tilth. Adoption of NT technology gives significant savings in energy for farmers and in 2006 it is estimated

[8] http://www.hort.purdue.edu/newcrop/duke_energy/acacia_albida.html#Uses

that 4.0 of the 13.5 million hectares of rice-wheat in the Indo-Gangetic Plains of South Asia used NT wheat (RWC website[9]). There were also savings in water pumping (much of the wheat acreage is irrigated) since water flows more rapidly across no-tilled fields compared to ploughed fields. Fertilizer efficiency also increased because the nitrogen and phosphorus inputs were drilled with the NT equipment rather than broadcast as in conventionally tilled wheat plots. The hundred million hectares of NT reported for the World (Derpsch and Friedrich 2009) means large fossil fuel savings and reductions in greenhouse gas emissions. Yields have also not been sacrificed by adopting no-tillage and in fact they have been sustained and increased over time by this technology as a result of improved soil structure and health (Hobbs, 2007). In the rice-wheat cropping systems of South Asia, yields are higher than conventionally tilled plots (100-200 kg ha^{-1} more).

Enterprise diversity and value addition potential of AF systems

The increase in crop and product diversity possible with AF systems has been discussed previously. Sustainable agriculture has to be about increasing the value of farm production, this in turn will permit a more sustainable management of the soil. Wilkinson and Elevitch (2004) describe the situation with coffee growers in Kona, Hawaii who can increase their income by up to 15 times by processing, packaging and selling their own products. Value addition as a result of AF activities, be it specialty fruit production and marketing, wooden ornaments or organic produce (for example) needs to be carefully managed. Kantor (2004) suggests three keys to success:

- Offering high quality products. This will often require technical assistance with product development and a detailed knowledge of customer requirements.
- Good marketing. Market research will reveal the size of the potential clientele. It may also reveal the need to collaborate with other producers or retailers.
- Ensure sufficient capital is available. Start small and don't invest all in a risky venture. Seek help with business management training if that is needed.

It would seem that value addition of AF products offers great potential in many situations and can be one more way of putting a brake on the rural poverty spiral that so frustrates development efforts.

Reduction of risks and enhancement of resilience with CA and AF

By providing much greater environmental stability, both CA and AF offer sustainability of production, even when climatic change is making smallholder farming more risky. Eliminating soil erosion and improving the quality of agricultural soils through increases in SOM resulting from residue management and no mechanical tillage, means that crop production is more stable, nutrients are steadily supplied and soil moisture regimes can be sustained for longer periods.

Production system risks can be reduced and resilience enhanced in AF and CA systems by the observance of some fairly straight forward guidelines distilled by Roland Bunch and his colleagues[10]:

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[9] http://www.rwc.cgiar.org/Pub_Datasheets.asp accessed 5th November 2008
[10] http://newfarm.rodaleinstitute.org/features/1002/roland_bunch/index.shtml

- **Maximise organic matter production**. OM will dramatically improve the resilience of cop production to adverse conditions. Many cover crop and AF systems reduce the labour requirement for weed control, thereby increasing OM production while reducing costs.
- **Keep the soil covered**.
- **Do not till the soil**.
- **Maximise biodiversity.**
- **Supply crop nutrients largely through mulch**.

All these points will be familiar to CA and AF practitioners and it is interesting to note that empirical guidelines have emerged through years of observation of actual farm situations, most of them not previously described as either CA nor AF.

FAO's Sustainable Agriculture for Rural Development (SARD) projects

FAO has been active in many countries and several continents in promoting the concept of CA for SARD (http://www.fao.org/ag/ca/7.html). One flagship project in East Africa is the CA-SARD project which is being implemented in Kenya and Tanzania[11]. It is an important development which has led to awareness creation and adoption of CA in the East African region by smallholder farmers. The project uses a farmer field school (FFS) methodology to introduce the CA concept to farmer groups and has created awareness at the local, national and regional levels through training, farmer to farmer exchange visits, farmer field days, workshops and seminars. Through the FFS approach, the project has so far reached almost 10 thousand smallholder farmers and has resulted in a 60% adoption rate covering nearly 28 thousand acres[12] under CA. The project has also focused on training agricultural extension workers and by doing so has become a reference point for other projects in the region. The project has stimulated collaboration with the private sector, especially with regard to CA equipment manufacturers and importers some of whom are now beginning to supply the emerging East African market. This aspect will now be discussed in more detail.

The CA equipment supply situation in Africa is in stark contrast to the achievements in South America. CA equipment is still mostly being imported (from Brazil principally) rather than manufactured locally. But the indigenous manufacturing industry is in its infancy. In East Africa there are now several manufacturers making simple equipment, mainly based on Brazilian concepts – although the Zamwipe herbicide applicator made in Zambia is a notable exception to this. These include jab planters, animal-drawn planters and knife rollers. FAO's projects have included the provision of imported machinery for no-till planting, knife rollers and herbicide application sprayers for human and animal traction. However in order to make the adoption of the CA approach more sustainable, it is envisaged that procurement of such equipment would be better handled through the private sector. Looking further ahead, there is a desire that, in the medium to long term, such equipment should be manufactured in the East African Region in order to boost the rural industrial sector and create skilled employment. Uniquely the project has initiated a technology

[11] http://www.act-africa.org/ca-sard.html
[12] 1 acre ≈ 400m^2

exchange process between manufacturers from southern Brazil and their counreparts in East Africa.

The second phase of the CA-SARD Project has been designed to fulfil the following objectives (Apina and Sims, 2008):

- Expanded adoption of profitable CA practices in Kenya and Tanzania
- Enhanced supply and availability of CA tools and equipments for farmers, - especially through improved private sector participation and networking between Brazil and East Africa.
- Strengthened knowledge sharing and networking between Brazil and East-Africa.

In this context, FAO organized a study tour and trade mission in 2008 to take would-be East African entrepreneurs to Brazil to interact with their Brazilian homologues[13]. The purpose was to energize the East African CA equipment manufacturing sector to produce equipment adapted to their local conditions. Reduced tillage animal-drawn rippers are made extensively in East African countries together with sub-soilers for removing hardpans as a prerequisite to CA. Of course hoes and machetes are made industrially in a range of African countries, and are also imported into the region from China and India.

The African manufacturers' study tour to Brazil highlights that:

- Project farmer groups trigger demand; they also participate in testing and proposing modification of the equipment.
- CA farmers need constant updating on the most appropriate practices of crop rotation, crop establishment, soil cover maintenance and management. It is only when these principles are put into practice that the CA equipment manufacturers will have a viable market for their products.
- An increasing demand is essential for batch production of CA equipment, and then to switch from batch production to more continuous production.
- A functioning support system (inputs, services, technical assistance, farm power availability) is vital for successful adoption and application in the long term.

In the final analysis only the availability of suitable equipment makes CA a viable cropping system which at the same time facilitates a closer integration of cropping systems with trees and an integrated AF system with low soil disturbance accomplished by no-till seeding and planting equipment.

Conclusions: Complementary CA and AF for broader synergistic impact

The exploration of the many facets of CA and AF in this paper has led us to the following conclusions on the highly desirable compatibility and complementarity that exists between the two connected paradigms:

- ➢ Both AF and CA seek to emulate natural recycling mechanisms and other ecosystem services (especially the elimination of soil erosion) found in forests.
- ➢ Both CA and AF promote soil health and biodiversity and so both will enhance soil fertility and hence its productive capacity.

[13] http://www.act-africa.org/publication/LAB/docs/CA_IAPAR_Proceedings.pdf

- AF systems (especially versions of alley cropping or live fences with leguminous tree species) produce nutritious browse which can alleviate pressure on cover crops. Free grazing of cover crops after main crop harvest is one of the major constraints to CA adoption in SSA.
- AF systems neatly complement CA systems in the provision of soil cover, animal feed, nutrients, household fuel, hillside protection against soil erosion and wind erosion control through shelter belts.
- Carbon sequestration, a key weapon in the fight for climate change mitigation, is vastly enhanced both in the soil (through no-till) and biomass (principally in trees and shrubs).
- Adaptation to climate change is facilitated by the increased water infiltration and storage in soils under CA and AF systems. Improved soil structure as a result of no-till and increases micro-faunal activity improve infiltration whilst increased SOM improves holding capacity.
- Degraded land is best rehabilitated with AF systems in conjunction with CA (which is better designed to perform under good soil conditions). Soil protection and anchorage through the establishment of tree species whilst maintaining cover and eliminating tillage with CA is a logical solution to rehabilitation.
- Crop and enterprise diversification are encouraged by CA and AF. One of the key components of CA is the use of crop rotations (for both main and cover crops) to exploit different soil strata and so recycle more nutrients. More and different crops can facilitate growth into new enterprises, such as livestock production. AF has vast scope for diversifying into fruit and timber production as well as livestock to exploit the additional feed produced.
- Family livelihoods are improved through CA and AF as labour requirements for soil preparation and weeding are reduced, crop production is increased and so incomes can be raised. Diversification of crops leads to better diets and a more constant supply of food crops throughout the year.
- The policy implications for developing country governments are clear: both CA and AF should be actively supported through incentive programmes (e.g. easier access to essential inputs), training programmes (for extension agents and farmers), and encouraging and nourishing the formation of farmer self-help groups (such as FFS). These ideas are encapsulated in the declaration following the IV World Congress on Conservation Agriculture held in New Delhi, India in February 2009[14].

[14] http://www.fao.org/ag/ca/doc/NewDelhiDeclarationCA.pdf

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