23
PERENNIAL CROPS AND TREES: TARGETING THE OPPORTUNITIES WITHIN A FARMING SYSTEMS CONTEXT

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INTRODUCTION: THE SEARCH FOR SUSTAINABILITY

Sustainable and resilient intensification of farming systems during the coming decades is a central challenge of our times. Almost half the world — over 3 billion people — live on less than US$2.50 per day; and approximately 1.3 billion, or about 22 percent of the population, consume less than US$1.25 per day (Chen and Ravallion, 2012). The immediate imperative is improving the household food security, incomes and livelihoods of the 1.3 billion poor: and the future challenge is to expand food production in order to feed the forecasted 9 billion consumers in 2050.

Economic growth is necessary to reduce poverty and food insecurity, but it is not sufficient (FAO, 2012). The majority of extremely poor households depend on agriculture for a significant part of their livelihoods, so it is not surprising that agricultural development is particularly effective in stimulating economic growth and reducing hunger and malnutrition (World Bank, 2008). Smallholder-based agricultural growth increases returns to labour and generates employment, especially for poor women. Dixon *et al.* (2001) identified five pathways by which farm households increase income and escape poverty: intensification (of existing patterns of production), diversification (sometimes bundled with intensification), expansion of operated farm size, increased off-farm income and exit from agriculture. Some recent improvement in household food security is reflected in the Global Hunger Index (IFPRI, 2013), but the progress is uneven and natural resources which underpin future agricultural productivity and food production are under increasing pressure.

Sustainability is a major concern given the pressure on land, water and energy resources (Lee and Barrett, 2001). Alongside the competition from other sectors for land, water and energy resources, the land frontier is approaching closure (Deininger and Byerlee, 2011). The pressure on land, water, energy and food is reflected in increasing prices during the recent past, notably increased resource valuations, the food price spike of 2008 and the forecasts of higher and more volatile food prices in coming decades.

The roadmap to achieve sustainable intensification is much debated (GO-Science, 2009; Tillman *et al.* 2011). The historic doubling of food production over the last four decades in Asia, largely due to the Green Revolution, was achieved through yield increases with limited additional land and water inputs, stemming from improved varieties complemented by improved fertilizer and crop management and functioning institutions and policies (Evenson and Gollin, 2003). The intensification of cropping systems through the Green Revolution was initially concentrated in well-watered areas with good connections to markets; and thus the initial livelihood benefits tended to be local whereas the food security dividends were regional or national. The Green Revolution was just one example of technology-driven changes which underpinned the growing intensification and differentiation of farming systems.

In relation to food production, recent analysis show significant variation of growth in total factor productivity across and within countries (Fuglie and Wang, 2012). Other analyses show growing concentrations of food production in a small number of annual commodities. For example, maize, wheat and rice production expanded relative to coarse grains and tubers; and chicken and pig production grew relative to cattle, sheep and goats (Tillman *et al.* 2011). However, even the growth in yield of the preferred cereal grains (roughly 40 kg/ha/y for wheat, 52 kg/ha/y for rice and 64 kg/ha/y for maize) lags behind growth in demand. Furthermore, there is evidence of some slowdown of annual cereal yield growth (Cassman, 2011). Moreover, in most food crop improvement programmes, the characteristic of perenniality has been neglected or removed through selection for yield. Over time, the role of perennials in food production has progressively diminished.

Quite apart from the core goals of global food security and economic growth, there are a spectrum of ecosystem services which are relevant to the search for inclusive sustainability – for example, biodiversity, water yield and purification and carbon sequestration (Asbjornsen *et al.* 2013). The authors are not aware of studies which compare the losses of annual and perennial species, but suspect that the former are more vulnerable to loss than the latter. Conversely, farmer re-vegetation initiatives show that the re-establishment of perennials is more challenging than for annuals. From the perspective of agro-ecosystem integrity and resilience, we argue that perennials tend to stabilize and enhance agro-ecosystem functions. This characteristic is critical for human outcomes, as the variability of productivity is a major source of the persistence of poverty, and also of 'new' poverty as households are stripped of assets and slide into poverty during (increasingly frequent) droughts. The important and well known ecosystem functions of perennials include increasing habitat niches for biodiversity (including crop pest predator habitats), reduced soil erosion and enhanced soil organic matter and moisture infiltration and storage, microclimate buffering, and greater above- and below-ground carbon sequestration.

As noted by other papers in this volume, perennial crops, pastures and trees potentially offer technical advantages for increased sustainable and resilient agricultural production (where agriculture is taken in the broad sense of crops, livestock, trees and fish). However, perennials must fit within farming systems which are shaped by agro-ecological and socio-economic factors. The following sections examine the added value from 'perenniality' (i.e., the functions potentially associated with perennial crops, pastures and trees) in eco-systems and farming systems, and identify a number of farming systems where perennials may have particular advantages. The adoption of perennials has implications for household livelihood improvement pathways. Because the future added-value of perennials depends very much on the evolution of farming systems, the main drivers of farming systems change are considered.

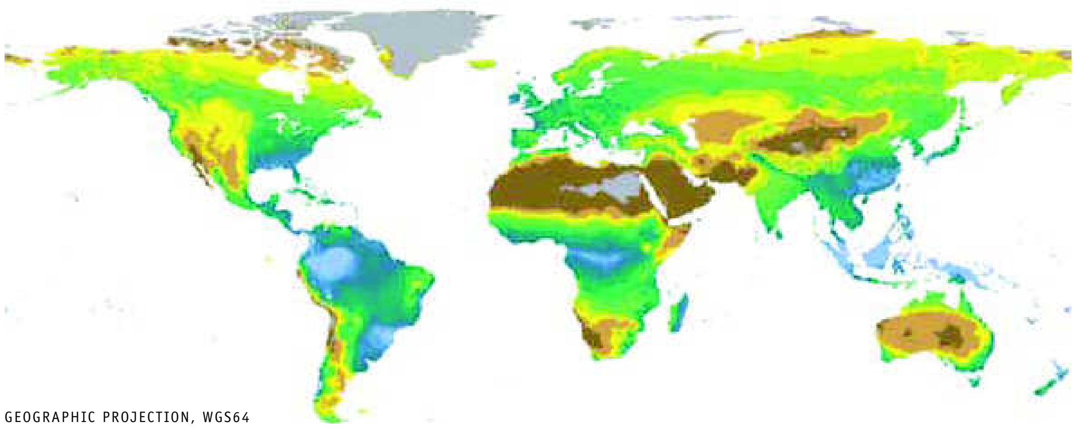
GEOGRAPHIC DISTRIBUTION OF FARMING SYSTEMS

Geography plays an important underlying role in the distribution of production and purchasing endowments. Except for irrigated areas, the average length of the growing period given precipitation, soils and temperatures is a major determinant of the potential productivity of rainfed crops, pastures and trees. Figure 1 illustrates the uneven distribution of lengh of the growing period across the surface of the globe. Moreover, the gaps between the achievable and actual yields of food crops are large in many environments especially in developing countries (Waddington *et al.* 2010).

FIGURE 1. GLOBAL DISTRIBUTION OF LENGTH OF GROWING PERIOD

GAEZ
Global Agro-Ecological Zones

REFERENCE LENGTH OF GROWING PERIOD ZONES (BASELINE 1961-1990)



GEOGRAPHIC PROJECTION, WGS64
resolution: 5arc-minute

0 3 900 7 800 15 600

DIMENSIONS

CROP	not applicable
WATER SUPPLY	not applicable
INPUT LEVEL	not applicable
YEAR	baseline period 1961-1990
SCENARIO	not applicable
CO2 FERTILIZATION	not applicable
VARIABLES	not applicable

LEGEND

0.0: background	9.0: 210–239 days
1.0: 0 days	10.0: 240–269 days
2.0: 1–29 days	11.0: 270–299 days
3.0: 30–59 days	12.0: 300–329 days
4.0: 60–89 days	13.0: 330–364 days
5.0: 90–119 days	14.0: 0–365 -days
6.0: 120–149 days	15.0: 0–365 days
7.0: 150–179 days	16.0: 0–365 +days
8.0: 180–209 days	

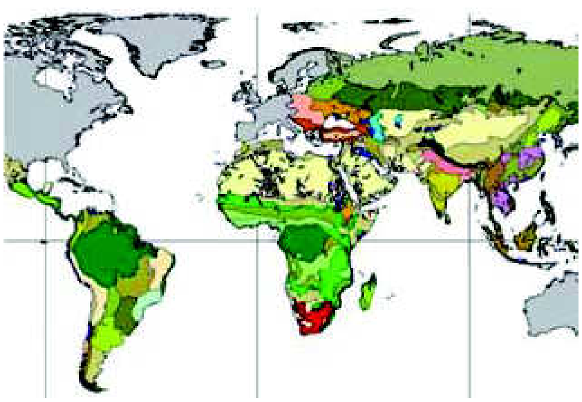
The various agro-ecologies are overlain by a mosaic of human settlement patterns that creates a multitude of diverse farming systems. Combining length of growing period and market access creates a pair of criteria which shape the land use, farming systems and livelihoods patterns of farmers in all countries. Following Dixon *et al.* (2001), a farming systems is defined as: 'a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. Depending on the scale of the analysis, a farming system can encompass a few dozen or many millions of households.'

At different scales, the concept would be applied in different ways – and heterogeneity would be apparent in different ways. Dixon *et al.* (2001) defined five dozen or so broad farming systems across six developing regions. Following the above concept, agro-ecology and socioeconomics shape crop, livestock and other farming system characteristics. Labour is an important household resource, and so off-farm employment is considered alongside crop and livestock production on the farm, and also domestic labour requirements, for example in the farm household. Each farming system has its own structure and function (Allan, 1965; Ruthenberg, 1971). There is remarkable diversity of farming systems in all regions of the world – ranging from productive banana-maize-coffee systems in the east African highlands to nomadic pastoralism of Central Asia to the maize soybean systems of the great plains of the United States. Figure 2 illustrates the five dozen most important farming systems across six developing regions of the world; much of the diversity of OECD agricultures can be captured in another couple of dozen farming systems.

FIGURE 2. DISTRIBUTION OF MAJOR FARMING SYSTEMS ACROSS DEVELOPING REGIONS

See Dixon *et al.* 2001 for a full description.

FARMING SYSTEMS IN DEVELOPING REGIONS



DRIVERS OF THE CHANGE

- Population
- Resources, climate
- Energy
- Science, technology
- Markets
- Institutions, policies
- Information

Source: Dixon et al., 2001, www.fao.org/farming systems/

These farming systems can be grouped into the following eight classes in both developing and developed countries:

- Irrigated farming systems, embracing a broad range of food and cash crop production, often for sale;
- Wetland rice based farming systems, dependent upon monsoon rains supplemented by irrigation;
- Rainfed farming systems in humid areas of high resource potential, characterised by a crop activity (notably root crops, cereals, industrial tree crops – both small scale and plantation – and commercial horticulture) or mixed crop-livestock systems;
- Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock systems;
- Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock-tree and pastoral systems merging into sparse and often dispersed systems with very low current productivity or potential because of extreme aridity or cold;
- Dualistic (mixed large commercial and smallholder) farming systems, across a variety of ecologies and with diverse production patterns;
- Coastal artisanal fishing, often with mixed farming systems; and
- Urban-based agriculture

Perennials offer different advantages within each of these system categories, as examined in the next section.

FITTING PERENNIALS INTO FARMING SYSTEMS

In farming systems, many perennials foster nutrient cycling, reduce wind effects, curtail soil erosion, and improve the micro-climate. Trees represent a class of farm asset that can be liquidated for capital (a 'bank') in times of need – which parallels the narrative around livestock as another easily saleable class of asset. Such asset accumulation is extremely critical to smallholders because many lack access to formal financial markets. Also, the inclusion/expansion of perennial grains or woody perennials in farming systems is a form of income and asset diversification that enhances livelihood resilience and reduces risk. Diversification of farm household activities is a very effective aspect of poverty escape strategies for farm households in many different farming systems, and is often more effective and dependable than intensification. Many perennials offer multiple products, which is an aspect that is particularly attractive to smallholders. For example, perennial rice could produce grain, forage and ecosystem services (e.g. carbon, reduced water erosion). Similarly, agroforestry trees may simultaneously provide fodder, fuelwood energy for the household and/or for sale, construction material, and ecosystem services in addition to high-value products that are produced for consumption and sale.

The production constraints and opportunities in farming systems are rapidly changing, with urbanizing markets, climatic variability and labour shortages growing in importance. Perennials are critical for both capturing new opportunities and for overcoming these constraints. Market constraints are generally declining for smallholder farming populations as infrastructure gradually improves and national, regional and global markets grow. This plays to the advantage of tree products. Perennial grains will reduce field labour requirements, and thus reduce women's labour burden.

We will now examine the present and future role of perennials in the generic classes of global farming systems, as summarized in Table 1.

TABLE 1. PRESENT AND POTENTIAL ROLES OF PERENNIALS IN DIFFERENT FARMING SYSTEMS CLASSES

CLASS OF FARMING SYSTEM	ROLES OF PERENNIAL GRAINS	ROLES OF PERENNIAL PASTURES	ROLES OF WOODY PERENNIALS
Irrigated farming systems, embracing a broad range of food and cash crop production, often for sale.	Limited role until perennial grains' agronomic performance is equivalent to annuals.	Role as a break crop or where livestock (especially dairy) is profitable.	Major role as high-value irrigated vines and fruits; significant roles along bunds, canals and access tracks; major role as intercrops (e.g. wheat-poplar systems), potential role as fertilizer trees and green manures, e.g. Faidherbia, Tephrosia.
Wetland rice based farming systems, dependent upon monsoon rains supplemented by irrigation.	Limited role until perennial grains' agronomic performance is equivalent to annuals.	Limited role for perennial pastures – but significant role for annual forages.	Significant role along bunds, canals and access tracks; high-value trees on mounds within fields (e.g. fruit crops), potential as fertilizer trees and green manures, e.g. *Faidherbia, sesbania*.
Rainfed farming systems in humid areas of high resource potential, characterised by a crop activity (notably root crops, cereals, industrial tree crops – both small scale and plantation – and commercial horticulture), or mixed crop-livestock systems.	Potential role for dual purpose grain/grazing, or as intercrop in tree crops.	Major role for pastures in livestock and crop-livestock systems.	Major role as a diverse range of agroforestry systems for production of fruits, medicinals and neutraceuticals, export commodities (e.g. coffee), high-quality fodder, timber and pole production, fertilizer tree integration.
Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock systems.	Major role for triple purpose erosion control, grazing and grain especially on steep slopes where annual crop establishment would not be sustainable, e.g. p-rice, p-sorghum.	Major role for pastures in livestock and crop-livestock systems in order to control erosion.	Major role for high value trees, timber, and forage trees and shrubs in livestock and crop-livestock systems, for sustainable production systems on steep land evolving out of unsustainable annual cropping, controlling soil erosion and degradation.

CLASS OF FARMING SYSTEM	ROLES OF PERENNIAL GRAINS	ROLES OF PERENNIAL PASTURES	ROLES OF WOODY PERENNIALS
Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock and pastoral systems merging into sparse and often dispersed systems with low productivity or potential because of extreme aridity or cold.	Potential role for double purpose salinity management and grain production, e.g. p-wheat.	Major role for pastures in livestock and agropastoral systems in order to make best use of available moisture.	Fundamental role as evergreen agriculture in dryland crop-livestock systems to enhance fodder production, improve crop yields through improved nutrient cycling, water holding capacity and buffering microclimate, reducing production vulnerability and increasing resilience. Diversification with high-value fruits, gums, etc. Special role of farmer-managed natural regeneration of Faidherbia and similar trees.
Dualistic (mixed large commercial and smallholder) farming systems, across a variety of ecologies and with diverse production patterns.	As above, depending on the agro-ecology and economic environment.	As above.	As above.
Coastal artisanal fishing, often mixed farming systems.	Potential role in harsh sandy environments where well established roots enable perennials to exploit deeper water.	Limited role because of frequently harsh agro-ecologies and prevalence of fish as an alternative protein source.	Major role for diverse home garden and agroforest systems of fruit, nut and forest species in coastal fishing-based environments.
Urban based, including peri-urban agriculture.	Limited role.	Limited role because of high value of land – thus other feeds used for livestock.	Major role for fruits for cash sales.

IRRIGATED FARMING SYSTEMS, EMBRACING A BROAD RANGE OF FOOD AND CASH CROP PRODUCTION, OFTEN FOR SALE

Farmers in the world's large-scale irrigated systems have generally been pursuing a strategy of crop intensification to maximize crop production through deploying the most advanced genetics, fertilization, pest management, and water management practices available. In areas where these technologies have been exploited to their fullest, the yield gap has been largely closed and only incremental gains are foreseen from intensification. Thus, their attention has been turning to reducing labour costs and to exploring ways to diversify production of enterprises that can provide new and more lucrative opportunities for income gains and income stability. The introduction of perennial varieties of their annual crops (rice, wheat, maize, etc.) could potentially help them achieve reduced labour and other production costs, when and if, agronomically superior varieties become available. With the possible exception of rice, these possibilities appear to be decades away.

Perennial forages play a niche role in some irrigated systems, often underpinning dairy farming and occasionally the fattening of ruminants. For example, berseem clover is a common irrigated forage in the Nile Delta or Wadi Haramout in Yemen. Irrigated grasses and alfalfa are grown for similar purposes in the United States and Australia, but are not yet widespread in irrigated systems in developing countries.

In the meantime, many irrigated farmers, particularly small-scale producers in the tropics, are avidly exploring enterprises that will diversify their income streams, and reduce their current levels of risk dependency on one or very few irrigated crops. This has led to the integration of higher-value crops in their irrigated systems, including fruit trees, vegetables and the like, often partially replacing their irrigated food crops with these alternatives. There has also been a trend toward growing trees for lumber, roundwood for veneer, construction poles, and other wood products.

One example of this has been the trend toward producing tree enterprises on irrigated land in northern India, where considerable areas of irrigated land has now been shifted into wood production. In some systems, timber trees such as poplar have been integrated in irrigated wheat production, improving the land equivalent ratios on the farm, and the overall annual income generated from the land. And in many other areas of the tropics, irrigated land has been shifted into high-value fruit tree production, particularly in countries where the local demand for fruits has increased and/or export markets have opened up, such as in the Sahel. These trends are accelerating in some countries.

Another opportunity that farmers have is to make better use of the non-irrigated portions of their land in the surroundings of irrigated fields. Increasingly, these portions of the farm (roadways, dikes, pathways, and unirrigated corners) are being planted with trees for asset-building, fruit production, environmental amenity, and windbreak microclimate functions to reduce crop water stress. The latter is a particularly important adaptation to the increased temperatures and longer and more severe drought events that are being observed in many areas. The role of perennials in micro-climate buffering will become a major area of interest in climate change adaptation in the future.

WETLAND RICE-BASED FARMING SYSTEMS, DEPENDENT UPON MONSOON RAINS SUPPLEMENTED BY IRRIGATION

Wetland rice systems are a class of irrigated systems where the land is waterlogged and/or under shallow flooding for a portion of the year; such agro-ecosystems are eminently suitable for wetland rice cultivation which has great cultural value in much of Asia. As noted above, the introduction of perennial rice might reduce labour and other production costs, but agronomically superior varieties are not yet available and so we do not anticipate widespread use of perennial rice in wetland rice systems in the near future. The availability of markets for milk and meat have provided incentives for the limited adoption of annual forages in some locations, but there seem to be weaker incentives for the adoption of perennial grasses or leguminous forages.

Naturally, such ecological conditions present farmers with considerable challenges in introducing and managing perennials directly in their rice fields. Nevertheless, opportunities abound. For example, innovative rice farmers in Indonesia, Thailand and Viet Nam are introducing high-value fruit trees directly into their irrigated fields by constructing mounds of soil in a grid pattern that enable them to culture fruit trees and avoid waterlogging the trees while providing them with a highly favourable rooting environment for fast and vigorous growth. This is a variation of the traditional bed and ditch system of rice-growing that became popular in Bangladesh and Indonesia as a means to use waterlogged rice soils for crop and tree diversification.

Many tree species have an inherent genetic degree of waterlogging tolerance. This has provided the basis for the selection of species, particularly timber, fodder and fuelwood-bearing trees that can be produced very successfully in rice fields, particularly in systems where the land is only waterlogged for less than half the year. Bangladesh has been a leader in the testing and incorporation of such species into rice production systems. Vigorous pruning of the trees during the rice-growing season yields fuelwood and fodder while minimizing competition for light, nutrients and water with the rice crops, thus achieving substantial overall income benefits.

Agroforestry trees are increasingly being deployed to reduce waterlogging and salinization of soils in the vicinity of irrigation canals with blocked drainage systems. Rice scientists are also observing that in many situations, excessive soil compaction limits the farmers' flexibility in the preparation of their rice fields for direct-seeding and limited irrigation regimes (Buresh, personal communication. 2013). This has stimulated interest in the possible role of trees in creating soil physical conditions that would enhance the success of these water-saving practices by enhancing field drainage conditions, particularly during land preparation. The choice of tree species with the appropriate rooting dynamics to provide this service role along with the provision of income-generating products could be a suitable approach to overcoming this drainage constraint. Further research in this area is anticipated.

Rainfed and partially irrigated rice-based systems are commonly prone to highly variable yields due to drought stress and flooding events. Thus, cash investments in inorganic fertilizer use, is a risky proposition for smallholder farmers facing these constraints over a huge proportion of the world's ricelands. Practices that would enhance the provision of biological fertilization with minimal labour inputs would be of substantive value in these situations.

On the rice-growing floodplains of the Senegal River, farmers have maintained a fairly dense population of the native tree species *Faidherbia albida*, which is indigenous to these environments. It is a highly tolerant to waterlogging, nitrogen-fixing species that displays reverse phenology, meaning that it is dormant during the rice-growing season, producing minimal shade. These observations have led to the hypothesis that such a compatible species might be the basis for a transformative type of rice-tree production system that would provide an abundant source of biofertilizer (particularly nitrogen) as it sheds its leaves at the beginning of the rain season, and would provide a source of fuelwood and fodder during the dry season, sustaining ruminant livestock in the system.

Rice production systems have always been particularly non-diverse crop production systems because of their unique hydrological situation. But clearly there is ample opportunity to foresee the diversification of these systems through the incorporation of a wide range of perennial options if researchers and extensionists were to pay more attention to the range of farmer innovations that have already pointed the way toward their future transformation.

RAINFED FARMING SYSTEMS IN HUMID AREAS OF HIGH RESOURCE POTENTIAL

Agricultural practices like agroforestry, introducing hedges, low and no tillage and cover crops have an important potential to increase carbon sequestration in rainfed farming systems. Aertsens *et al.* (2013) found that this would correspond to 37 percent of all CO_2-equivalent emissions in the EU in 2007. They found that the introduction of agroforestry was the measure with the highest potential to sequester carbon in European agriculture. Its potential was estimated to be 90 percent of the total sequestration potential of the various practices studied. Taking account only of the value for climate change mitigation, they found that the introduction of agroforestry is estimated to have a value of 282/ha in 2012, and that this will gradually increase to 1 007/ha in 2030. This implies that there is a very large potential benefit for society in general and for the agricultural sector in particular. At the European level, during the past few years, policy makers have recognized the important benefits of agroforestry, and rural development programmes some European countries now support farmers to introduce agroforestry. But the current level of support is still only a small fraction of the societal value. Aertsents *et al.* (2103) posited that if this value would be fully recognized by internalizing the positive externality, agroforestry will be introduced to a very large extent in the next decades, in Europe and the rest of the world, and that this will dramatically change rural landscapes.

In Africa, the Maize-Mixed Farming System is a dominant one, extending over much of eastern and southern Africa. It has a greater agricultural population and more poverty than any of the other farming systems in Africa, and serves as the food basket as well as driver of agricultural growth and food security in the region. Conservation agriculture (CA) is currently being promoted at a major scale in African maize-growing systems. CA involves minimum soil disturbance, crop residue retention, and crop rotation.

However, the uptake of CA in Africa, and in the rainfed upland areas of Asia, has been modest so far. The short-term advantages observed where CA is currently practiced are earlier planting to enable better use of seasonal rainfall, and increased rainwater conservation in the soil to better tide crops over during drought periods (Rockstrom *et al.* 2009). But there are a number of unique constraints to smallholder adoption of CA that are retarding its more rapid uptake. Most important among these are competing uses for crop residues where livestock production is common, inadequate biomass accumulation of cover crops in the off-season, increased labour demands for weeding when herbicides are not used, variable yield results across soil types, and the need for adequate application of organic and inorganic nutrients.

Recently, the CA and agroforestry research and development communities recognized the value of integrating fertilizer trees and shrubs into systems of 'conservation agriculture with trees' (CAWT). These enhance both fodder production and soil fertility (FAO, 2010, FAO, 2011). Practical systems for intercropping fertilizer trees in maize farming have been developed and are now being extended to hundreds of thousands of farmers in Malawi and Zambia (Ajayi *et al.* 2011; Garrity *et al.* 2010). The portfolio of options includes intercropping maize with *Gliricidia sepium*, *Tephrosia candida*, pigeon peas or forage legumes, or using trees such as *Sesbania sesban* as an improved fallow.

One particularly promising system is the integration of the *Faidherbia albida* in crop fields at a 10 m by 10 m spacing. *Faidherbia* is an indigenous African acacia that is widespread on millions of farmers' fields throughout the eastern, western, and southern regions of the continent. It is highly compatible with food crops because it is dormant during the rainy season, and it exhibits minimal competition, while enhancing yields and soil health (Barnes and Fagg, 2003). Several tonnes of additional biomass can be generated annually per hectare to accelerate soil fertility replenishment, provide additional livestock fodder. Numerous publications have recorded increases in maize grain yield when it grown in association with Faidherbia, ranging from 6 percent to more than 200 percent (Barnes and Fagg, 2003), depending on the age and density of trees, agronomic practices used, and the weather conditions. These CAWT systems are a type of Evergreen Agriculture in which trees are managed as an integral element of crop fields (Garrity *et al.* 2013).

Of course, commercial tree crops such cocoa, coffee, rubber and oilpalm are concentrated in humid rainfed farming systems such as in coastal West Africa, Malaysia of Kalimantan, Indonesia. Often the tree crop is grown as a monoculture, but increasingly farmers are realizing additional income by inter-cropping during establishment with annual food or high value crops (e.g. vegetables) or perennials pastures and ground cover during later years.

In general, incorporating trees into crop farming may confer sustainability benefits through ecological intensification. They may increase the resilience of the farm enterprise to climate change through greater drought resilience, and they sequester more carbon. Conventional CA systems tend to sequester a maximum of 0.2–0.4 tonnes C/ha/yr. CAWT systems may accumulate carbon both above and below-ground in the range of 2–4 tonnes C/ha/y, roughly an order of magnitude higher than with CA alone (Garrity *et al.* 2010). This is particularly true for systems incorporating fertilizer trees such as Faidherbia or Gliricidia (Makumba *et al.* 2007). Consequently, there is considerable interest in the development of reward systems to channel carbon offset payments from developed countries to stimulate more carbon sequestration in African food crop systems while simultaneously enhancing the livelihoods of smallholders and the environment. These investments will encourage development pathways resulting in higher carbon stocks at a whole landscape scale.

CAWT systems are now attracting considerable research and extension attention. Their success will depend on the use of a wider range of tree species for varied agro-ecologies, higher quality tree germplasm, better tree seed dissemination systems, and further improvements in tree propagation and establishment methods. The optimum tree densities for different CAWT systems have yet to be fully understood, and the best practices in exploiting the soil fertility synergies between organic and inorganic nutrient sources need to be elucidated. Targeting and scaling-up methodologies deserve particular attention. These need to be supported by work to reverse detrimental policy frameworks in some countries that may discourage farmers from cultivating trees on farms. Also, active farmer organizations have always been instrumental in the development and spread of CA. Thus, the growing interest in Landcare for grassroots mobilization in Africa and Asia can provide a particularly suitable approach for the engagement of farming communities in the refinement and spread of CAWT.

RAINFED FARMING SYSTEMS IN STEEP AND HIGHLAND AREAS

This farming system has the most to gain from increased perennialization, associated in large measure with the ability of perennials to provide surface cover and to drastically reduce erosion. Hill farming systems in southern China and the Mekong might become the first beneficiaries from perennial rice, producing both biomass and grain while stabilizing the ecosystem and reducing labour requirements in areas with strong market demand for ruminant products. In this role, perennial rice might compete with perennial forages which are increasingly being intensively managed in sloping land agriculture as in the Philippines and much of south-east Asia. Of course, similar roles might be identified in sub-tropical and sub-tropical and temperate zones.

Subsistence annual cropping systems have spread to many steeply sloping lands in the tropical developing countries as a consequence of poverty, unemployment, and the shortage of land. Continuous cropping on steep lands generally results in enormous rates of soil erosion and rapid land degradation. Perennial crop systems have proven to be a much more sustainable land use in these ecosystems. Tree crops such as rubber, oil palm, and cocoa have been expanding rapidly on these sloping lands during recent decades, particularly in Southeast Asia.

In eastern Africa the farming systems have also come to be dominated by perennial crops, particularly coffee, tea and cooking bananas (Garrity, 2012). These areas now support some of the highest rural population densities in sub-Saharan Africa. They also exhibit some of the highest agricultural potential. They have been a natural experiment in the interaction between population growth, declining farm sizes, and the intensification of farming systems., as sustainable intensification runs up against extreme limits to minimum farm sizes, and as well as the possibilities and limits of farming systems commercialization. They are now characterized as permanent systems and fallowing for soil regeneration is no longer possible (Carswell, 2002). The liberalization of markets in the late 1990's now offers a principal pathway for further intensification of these farming systems.

RAINFED FARMING SYSTEMS IN THE DRYLANDS

Because of the moisture limitations and climatic variability in semi-arid areas, perennial crops, pastures and trees have a natural advantage and often produce more biomass than annual plants (the converse can be true of arid zones). Sorghums and millets are common food grain crops in the tropical drylands, yet often fail because of establishment drought. Hence perennial sorghum (or millet) might be attractive to many risk-averse smallholder farmers. The farming systems of the drylands generally feature the integration of crops and livestock, with crop residues representing and important source of fodder for ruminants. In this context, dual purpose grain/graze cereal or legume crops would have advantages; and so too a stay-green trait for deep-rooted perennials which could maintain forage quality in the early part of the dry season.

Of course perennial natural pastures are the mainstay for livestock industries in most dryland areas. The ecosystem services from rangelands are often under-estimated, not least erosion control and carbon sequestration. However, the importance of small scale irrigation in the drylands is often overlooked. Such highly productive patches stabilize farm-household livelihoods, whether used for crop or forage production – and for the latter perennial grass and legume forages, mixed or as a monoculture, would have many advantages.

The retention of trees in dryland crop fields in the tropics has been a widespread traditional practice in semi-arid areas. In the Sahelian region these agroforestry parkland systems became common as agriculture gradually intensified (Boffa, 1999). The trees are an integral part of the agricultural system, providing food, fuel, fodder, medicinals, wood for buildings, cash commodities, as well as contributing to soil fertility, water conservation, and environmental protection. However, demographic, economic, environmental and social developments during the past 40 years have put pressure on traditional land-use systems, and concerns have intensified about the steady degradation of land health in the semi-arid dryland agricultural systems in the tropics. This has turned attention to the ways that trees and shrubs can be more successfully integrated into food crop systems on a larger scale, in order to regenerate the soil health, increase annual crop yields, and diversify livelihoods, building on the knowledge and practices of dryland farmers themselves.

A globally relevant model of positive action has evolved in Niger. Since 1985, more than a million rural households in Niger have protected and managed the natural regeneration of native trees, growing in farm fields across 5 million hectares. Nigerien farmers have added approximately 200 million additional trees across agricultural landscapes, which have directly contributed to the increased production of about 500 000 tonnes of grain per year, an amount sufficient to feed an additional 2.5 million people (Reij *et al.* 2009). The United States Geological Survey also recently mapped 450 000 hectares of newly created agroforestry parkland in the Seno Plains of Mali (Tappan, 2012). Farmers in Zambia and Malawi are also increasing the protection and management of trees on farms and increasing adoption of intercropping of nitrogen-fixing species, including the native tree *Faidherbia albida*. It is estimated that currently about 500 000 Malawian farmers have Faidherbia trees on their farms (Garrity *et al.* 2010). The majority of these trees grew through assisted natural regeneration of seedlings that emerged in farmers' fields.

POLICY CONSIDERATIONS

It is worthwhile considering the policy and institutional settings which will influence the spread of perennials and benefits therefrom. Of course, starting about 10 000 years ago annual crops began to progressively replace perennial food plants including grasses, tubers and fruit trees.

Much annual food crop production is supported, in principle or in practice, by public subsidies, e.g. seed, fertilizer and machinery subsidies. Thus, for widespread adoption of perennial food crops a 'level playing field' would be required – either through reduction of input subsidies or compensating subsidies to perennial crop, pasture and tree adoption. Of course, public support to perennials R&D would be important (and relatively easy to justify because perennials offer prospects of greater eco-system services than annuals). It should be recognized that many annual crops with high input levels provide incentives for private sector involvement, whereas perennial crops would generally require less management of seed/planting material and inputs.

Because of the complexity of farming systems incorporating perennials, research managers should support participatory research and development methods. Such methods might lead naturally to enrichment of farming systems rather than wholesale replacement of annual crops.

CONCLUSION

Perennials are increasingly appreciated as playing a major role in agricultural diversification, risk management and mitigation. This brief survey has highlighted some of the innovative ways that perennials are being deployed in major farming systems around the globe, and the rationale for this trend. Clearly, the potentials, resource pressures and intensification pathways vary across the different types of farming systems (Dixon *et al.* 2001). It is at the level of the farm system that the trade-offs between food security, livelihoods and adaptation to climate change become apparent. And the relative importance of poverty escape pathways varies across farming systems. For example intensification and enterprise diversification dominate poverty reduction in high potential pathways but off-farm income and exit from agriculture are important in low potential systems. These differences in pathways and tradeoffs should be reflected in the design of sustainable intensification research programmes and policies.

Growing concerns about how agriculture will adapt to climate change, how food security can be enhanced, extreme poverty eliminated, and how land degradation processes will be reversed, have accelerated efforts to advance the roles that woody perennials and perennial crops will play in the future of farming. Their role will be transformative over the medium to long term, but they represent opportunities that are often at odds with conventional path-dependent thinking. Research investments and agricultural policy continue to be overwhelmingly dominated by short-term interests. And the enormous opportunities that the perennialization of agriculture are opening up have yet to be translated into commensurate research and policy attention.

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