Agroforestry Solutions for Buffering Climate Variability and Adapting to Change

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14.1 Introduction

This chapter will focus on increasing the adaptive capacity of agricultural systems in tropical and subtropical regions through agroforestry. Agroforestry as a concept resists and tries to counteract the way agriculture has been segregated from forests and forestry. Understanding, using and improving agroforestry implies a focus on the interactions between trees, annual crops and domestic stock, given the local abiotic factors of climate, soils, water and nutrient balances, as well as the biotic context (pests, diseases, antagonists, predators, pollinators and dispersal agents), and the use of land, external inputs, labour and knowledge. We pose and review the hypothesis that the presence of trees increases the degree of buffering of climate variability from the perspective of an annual food crop, and that retention and the increase of trees in agricultural landscapes can be a relevant part of climate change adaptation strategies.

14.1.1 Intuitive appeal of linking trees to climate

People associate climate issues with trees. Tree planting as a ceremonial activity has intuitive appeal in the context of climate change and is popular among politicians who want to show that they are not just talking about climate, but are willing to act. At the micro-scale, this is a logical association, as we seek the shade of trees on a hot day, seek shelter under trees if surprised by a rainstorm (but some know that deep-rooted trees attract lightning), select tree-covered roads to cycle against the wind (if having grown up in a bicycle culture) and prefer trees around our houses to buffer both the heat of summer (or the day) and the cold of winter (or the night). Yet, trees have mostly been discussed in climate change in terms of their carbon storage and the contributions they make to the global carbon balance (Watson et al., 2000). Their more direct effect on micro- and mesoclimate is largely absent from the climate change debate, including that involving agriculture. This chapter will argue that important adaptive opportunities are missed if we continue to ignore trees in that context, as in a recent report by Beddington et al. (2011) and an overview by Vermeulen et al. (2012). The intuitive appeal of trees and tree planting may have to be channelled towards adaptation, however, rather than mitigation discussions of climate change (van Noordwijk et al., 2011a).

Path dependency of the international climate change discussion has led to a ‘firewall’ between the concepts and financing mechanisms of mitigation and adaptation.
When there was hope that mitigation efforts could contain global climate change to the level that adaptation would not be needed, this distinction made sense. However, the inadequacy of mitigation efforts implies that we are substantially beyond that option. Synergy of mitigation and adaptation actions across all sectors is needed, but in land use it has always been a very logical option (Verchot et al., 2007; van Noordwijk et al., 2010; Matocha et al., 2012). Recent support for agroforestry as a part of agricultural adaptation strategies (Schoeneberger et al., 2012; Munang et al., 2013) is moving in this direction as well, as is the interest in landscape approaches that will drive towards the integration of sectors and issues.

14.1.2 Absence of trees in current climate science

Climate science has been cognizant of the substantial impacts of trees on wind speed, humidity, temperature and even rainfall, but has chosen to standardize its measurement effort on open-field situations (above a short grass cover), where such ‘disturbing’ factors are minimized. Thus, all climate maps and all climate models calibrated on synoptic weather station data refer implicitly to a tree-less landscape. There has been considerable discussion on the ‘urban heat island’ effect in less green environments (Arnfield, 2003), but less on its counterpart ‘cool forest’ effect that complements it (Bonan, 2008). Local topography influences microclimatic differences in interaction with vegetation, as has been recognized by some ‘climate-smart’ landscape designs (Bonan, 2002). However, there have to date been no attempts, to our knowledge, to show climate maps of the same area with different degrees of tree cover, obtained by adding the microclimatic variation caused by tree cover to the open-field climate data and their predicted patterns of change from global circulation models (GCMs). From the data reviewed in this chapter, it is suggested that the impacts of local tree cover on major weather variables at local scales is substantial – and that variations in tree cover in an agricultural landscape may, for the next 30 years or so, exceed the predicted patterns of climate change on key climatic variables for many locations (van Noordwijk et al., 2010). A more directly empirical approach to the combination of local and global drivers of local climate change has been promoted by Pielke et al. (2007) and Bonan (2008). In the discussions of forest and climate, the net effects of changes in surface albedo and evaporative cooling imply that deforestation has a warming effect in the tropics, but can have a cooling effect at mid and high latitudes (Jackson et al., 2008; Swann et al., 2012).

14.1.3 Agroforestry as history and future of agricultural land use

Historically, agriculture in many parts of the world was compatible with the retention of valuable trees in cropped fields, and its impact on deforesting the world was gradual (Williams, 2006). It used only superficial soil tillage, usually in combination with a controlled fire that cleared the land but did not kill the larger trees (Cairns, 2007). In temperate zones with relatively mild climates, however, a different approach to growing crops emerged, ‘non-conservation agriculture without trees’, which was successful as it was readily scaled up, with horse-drawn ploughs replacing human tillage, and tractors with ever-more horse power, requiring the clearing of hedgerows and trees on field boundaries to make larger fields, drawing ever-deeper ploughs through a soil that responded by mineralizing a substantial part of its organic matter, feeding the crops. This yield benefit, however, was not sustainable, as it depleted the resource base – chemical fertilizer had to become the basis of plant nutrition. As tillage had killed many of the worms and other soil engineers, tillage became ‘necessary’ to create a structure compatible with crop roots. The trouble started when this tree-less, tillage-addicted form of agriculture became the norm, became known and taught worldwide as what
agriculture was and should be, and was extended to parts of the world with less benign climates. Conservation agriculture in landscapes with trees, maintaining soil organic matter content, is now seen as ‘climate-smart’ agriculture (McCarthy et al., 2011). An important part of the solutions sought are part of a landscape agroforestry approach.

The term ‘agroforestry’ was coined in the mid-1970s when the ‘green revolution’ experience and debate had made clear that its perspective on intensifying crop production worked well in specific environments but not elsewhere (King, 1979). While a parallel approach to large-scale plantation forestry had success in some areas, it ran into major social conflicts and issues over land rights elsewhere. The idea that crops and trees were not necessarily incompatible was revolutionary for academically trained agronomists, while trained foresters had a hard time in seeing that the local people were not their major problem. In many parts of the tropics, these perspectives appeared to be self-evident, if only one took a good look around. Trees and crops, farmers and forest could somehow work together.

Yet advances in understanding the biophysical (Ong and Huxley, 1996), ecological, social and economic aspects of tree–soil–crop interactions were slow to become mainstreamed in the world of ‘development’ and ‘modernization’. New forms of agroforestry, compatible with mechanization and focused on trees of high value, finally emerged in Europe, North America and Australia (Gordon and Newman, 1997; Eichhorn et al., 2006; Gold and Garrett, 2009) – challenging the rules and regulations that had been made on the concept of segregating trees and crops.

The climatic effects of trees vary with latitude, partly because the solar angle matters for the shade effect, while the windbreak effect operates at a near-zero angle of incidence at any latitude. Tree cover in agricultural landscapes, however, varies within the tropics as well. The scope of the additional adaptive benefits of enhancing agroforestry will be highest in areas that are currently low in tree cover, while in others retention is the first target. Analysis by Zomer et al. (2009) indicated that, globally, 46% of land classified as agricultural contained at least 10% tree cover, and in areas such as South-east Asia or Meso-America, half the agricultural land had at least 30% tree cover – sufficient to be classified as forest if it were not for the definitions of forestry that made agricultural use a disqualifying condition for land to be recorded as forest (de Foresta et al., 2013).

14.2 Supply and Demand of Buffering Functions in the Landscape

In the parklands of the Sahel (Africa), farmers have retained trees that provide edible fruits and grow their grain crops in between and underneath trees, despite the shortages of water that regularly occur during the growing season (Breman and Kessler, 1997; Boffa, 1999; Takimoto et al., 2008). Tree–soil–crop interactions in these systems, combining buffering and productivity, are a complex mixture of positive and negative effects, above and below ground (Kho, 2000; Kho et al., 2001).

The microclimatic effects of agroforestry have been studied through analysis of the energy and water balance for more than two decades (Monteith et al., 1991; Ong et al., 1991; Brenner, 1996). Analysis by Ong et al. (1991) suggested that atmospheric interactions in hedgerow cropping in the semi-arid tropics were positive but were of minor importance compared with below-ground, often competitive, interactions. Rao et al. (1997) concluded that the net positive effects of trees on crops were more likely in sequential rather than simultaneous agroforestry systems, as below-ground competition dominated tree–crop interactions for major food crops. When the focus of agroforestry research shifted from intensively mixed crop–hedgerow systems to field-boundary plantings of commercially important timber trees such as Grevillea robusta, a more positive evaluation of net above- plus below-ground interactions followed, even where maize was the
dominant food crop (Ong et al., 2000). While the relative importance of below-ground relationships is not contested (van Noordwijk et al., 2004a), current interest in the climate change sensitivity of crops may make temperature shifts of the order of 2°C more relevant than they may have appeared in the past (Vermeulen et al., 2012): 'Agricultural production is highly vulnerable even to 2°C (low-end) predictions for global mean temperatures in 2100, with major implications for rural poverty and for both rural and urban food security'.

Active and flexible shade management has a long history in major commercial tree crops such as tea, coffee and cacao (Beer, 1987; Beer et al., 1997; Lin, 2007; Tscharntke et al., 2011). Appreciation of trees for their microclimatic effects in sylvopastoral agroforestry systems has been clear. Tree shade in relation to the daily cycle of livestock activity and movement can reduce direct heat exposure of the animals, and hence their sensitivity to climate variability (Thornton et al., 2009). Ongoing pasture intensification that removes trees, however, increases exposure and vulnerability (Harvey et al., 2011). Buffering functions are being compromised, just as they are likely to be needed more. Landscape multifunctionality, as contrasted with specialized monocultures, can be analysed in terms of the provision of and need for buffering across the five capitals of livelihood systems (Bebbington, 1999).

Buffering = 1 – Variation-with/Variation-without

For river flow, a more specific buffering factor has been based on the temporal autocorrelation of rivers (van Noordwijk et al., 2011b); for a buffering factor of zero, daily river flow is fully random; for buffering factor one, it is perfectly constant, regardless of rainfall. For nutrients, buffering relates to the temporal pattern of crop needs and soil supply, exposing nutrients to leaching and atmospheric losses under temporary excess conditions (van Noordwijk and Cadisch, 2002). A direct role by which trees can influence the buffering of soil water supply is by increasing the effective soil depth in which water can be stored during rainfall excess in the early part of the growing season (Fig. 14.1) – as will be discussed in more detail below.

For economic portfolio effects in risk reduction, the degree of temporal correlation between commodity yields and/or prices determines combined variance, and thus buffer effects. Maintaining a diversified portfolio of activities is a safe and time-tested approach to reduce the risks (van Noordwijk et al., 1994). The inclusion of trees that provide annual harvests of fruits and/or long-term, high-value timber can reduce risk, even if the trade-off in resource capture is essentially neutral (Santos-Martin and van Noordwijk, 2011).
14.3 Trees Modifying Wind Speed

The older literature (Caborn, 1965; Forman, 1990) has already established the direct utility of using shelterbelts and windbreaks to modify microclimates, with implications for landscape designs that minimize vulnerability. The effects of windbreaks on wind speed have been quantified in various environments, and the consequences of the ongoing removal of hedgerows have been documented (Sánchez et al., 2010). A synthesis of older data by Nuberg and Bennell (2009) concluded that measurable reductions of wind speed could be expected from about 5 times the canopy height before and up to 20 times the tree canopy height after the trees in the direction of the wind, and that semi-transparent windbreaks were more effective than solid ones, as the latter might cause turbulence while the first could maintain laminar flow conditions (Cleugh, 1998). Models that include turbulence effects are now available (Yeh et al., 2010), and windbreak porosity can be easily quantified as a basis for optimizing management (Kenney, 1987). Connections are being made between the hedgerow fabric of landscapes and the social and policy dimensions (Larcher and Baudry, 2013).

Given the considerable benefits involved for orchard crops, the fine-tuning of recommendations to site-specific conditions is needed. Tamang et al. (2010), for example, installed automated weather stations on the leeside of single-row tree windbreaks in southern Florida, USA, and found the lowest wind speed (~5% of the open wind speed) at two to six times the distance of windbreak height, depending on tree species and porosity. They found statistically significant wind speed reduction up to 31 times the windbreak height.

14.4 Trees Buffering Temperature

While wind is a near-horizontal flux and tree effects can extend beyond 20 times the canopy height, the shading effect on
temperature is restricted to a few multiples of tree height, depending on the solar elevation (Kohli and Saini, 2003). Compared to open-field agriculture, all land-use systems with trees have a reduced daily amplitude of air temperature, with a gradual dampening of the amplitude within the top layers of the soil. An example of a data set from East Java (Fig. 14.2) shows a daily amplitude of air temperature in open-field agriculture of 10.7°C, in closed-canopy secondary (degraded) forest of 5.6°C and intermediate values for various types of agroforestry coffee-based systems. In the closed-canopy systems, the daily amplitude of soil temperature at 5 cm depth is less than 3°C, while it is up to 9°C in the open-field situation.

In related studies, Hairiah et al. (2006) compared the effects of shading on the litter layer soil temperature and its spatial variability in open- and closed-canopy coffee agroforestry systems in Lampung, with a natural forest comparison. Martius et al. (2004) measured the daily amplitude of temperature in the litter layer across various agroforestry systems and closed-canopy forest, and found that canopy closure marked a major shift in temperature regime with associated increase in the biomass of soil macrofauna.

Direct measurement with data loggers of temperature and air humidity in different positions with respect to trees in the parkland agroforestry systems of Sapone (Burkina Faso) gives evidence (Fig. 14.3) of the buffering effects of trees on maximum daily temperature (average 1°C up to 2.5°C on hot, cloudless days) and minimum air humidity (0–5%), with stronger differences on hotter and drier days.

Jonsson et al. (1999) reported that crops were less exposed to excessive temperature of above 40°C with 1–9 h week⁻¹ under karité and néré trees, against 27 h week⁻¹ in the open field. It is not quite clear which of the many ways of measuring temperature is the most relevant for predicting crop performance. In a *Grevillea*-based agroforestry system in semi-arid Kenya, the

![Fig. 14.2.](image)

**Fig. 14.2.** (a) Temperature profile during a daily cycle in different land cover types in an East Java mountain location (Ngantang, East Java, Indonesia), including simple shade and multi-strata coffee agroforestry systems, compared to (degraded) forest and open-field agriculture (data were averaged for dry season and rainy season measurements); (b) relationship, across seasons and land-use systems, between the daily amplitude of air temperature and temperature at 5, 15 or 25 cm depth in the soil.
mean maximum meristem temperature for maize in agroforestry systems was 5–6.0°C lower than for sole maize, depending on season (Lott et al., 2009).

Large effects of trees on temperature were reported in a study of urban trees in Bangalore (India), where street trees provided a maximum reduction in afternoon ambient air temperatures of 5.6°C, and of tarmac road surface temperatures of 27.5°C (Vailshery et al., 2013). Similar data can now be obtained directly from satellite spectral information. Lai et al. (2012) discussed the relation between near-ground air temperature \( T_a \) as measured in climate stations and land surface temperature \( T_s \) as derived from the moderate resolution imaging spectroradiometer (MODIS) instruments installed on the Aqua and Terra Earth observation satellites. Correlation coefficients of 0.91–0.96 were obtained, and the standard deviations of the differences between the two sets were 1.2–1.8°C. However, differences in spatial resolution, different sensitivity to soil moisture buffering and technical challenges in the correct interpretation of the satellite data remain. Cassidy et al. (2013) used MODIS satellite data to derive a daily pattern of surface temperatures over different land cover types in the Mekong region in Southeast Asia. They estimated a 15°C daily amplitude for an ambient air temperature and 10, 22, 25, 30 and 37°C for the surface temperature of secondary forest, a cassava crop (young stage), a fallow rice field grassy residue, bare land (ploughed field) and a tarmac road, respectively.
14.5 Trees Modifying Water Balance

14.5.1 Processes

Cannavo et al. (2011) considered the net effect of shade trees on the water balance of coffee production systems and found that a net increase in infiltration rate in the agroforestry version of coffee was linked to an effectively deeper soil system that provided a stronger buffer and reduced losses by leaching. Hydraulic lift, the transfer of water from relatively wet deeper layers to drier soil higher in the profile, has been described for both natural tree–grass mixtures and agroforestry systems (Richards and Caldwell, 1987; Dawson, 1993; Caldwell et al., 1998; Midwood et al., 1998; Norton and Hart, 1998; Zou et al., 2005; Hawkins et al., 2009). If the topsoil is re-wetted by rainfall, flow will be in the reverse direction (Hultine et al., 2004) and the term ‘hydraulic redistribution’ may describe the process irrespective of direction (Burgess et al., 1998; Smith et al., 1999; Brooks et al., 2002).

Nadezhdina et al. (2010) describe four types of hydraulic redistribution, including canopy capture of fog and transfer to drier soil layers. The physics are well understood, as the root–soil contact that allows the uptake of water to occur where the water potential inside the roots is more negative than that in soil cannot prevent water to enter the soil where the gradient in water potential is the reverse. Root shrinkage, reducing root–soil contact, and dieback can reduce water loss for the plant, but needs to be reversed if the soil re-wetted. Hydraulic redistribution may benefit the plant in two ways: it allows for higher daytime water uptake, using water that is brought to the well-rooted topsoil, and it facilitates nutrient uptake in situations where nutrients are in the topsoil but difficult to access because of low effective diffusion rates. These two benefits, however, are ‘public goods’ in the soil layer and other plants rooted in the re-wetted soil layers benefit as well.

Water vapour transport can play a dominant role in transport in the upper 15 cm, subject to strong day–night cycles in temperature, but root-based hydraulic redistribution likely dominates in deeper layers (Warren et al., 2011). Ludwig et al. (2003) found that hydraulic redistribution in Acacia tortilis could re-wet soil up to 10 m from the tree stem, but was absent in a dry year. The competitive effect of trees can outweigh the facilitation by hydraulic redistribution (Ludwig et al., 2004). Prieto et al. (2010) found that by restricting daytime tree transpiration, the net effect of hydraulic redistribution on soil water content could be increased. The total effects were found to depend on soil texture and associated soil physical properties. The role of sparse root systems in the subsoil in the overall water balance is much more than that expected; hydraulic equilibration effectively provides the roots with an opportunity to function for 24 h day$^{-1}$ rather than only during transpiration peak demand (Amenu and Kumar, 2008).

Sekiya et al. (2010) found that above-ground removal (pruning) of stems could enhance greatly the net positive effects on companion crops. Burgess (2011) described attempts to use such effects in designed agricultural intercropping patterns. Siriiri et al. (2013) reported that shoot and root pruning of Alnus acuminata and Sesbania sesban on terrace risers increased water content in the cropping area. Wang et al. (2011) found that hydraulic redistribution could have positive effects on transpiration and plant growth during regular dry seasons but negative effects on net primary productivity (NPP) under extreme droughts, such as those during El Niño years in the Amazon forest. The latter is due to more rapid depletion of the groundwater reserves, reaching the permanent wilting point earlier. Climatic limits to the potential positive effect of hydraulic redistribution can thus be defined on the basis of the required build-up of deep groundwater reserves (potentially concentrated in groundwater flows and allowing use at some distance from the source), and the relevance of wetter topsoil to survive dry spells.

The bumper harvests that can be obtained after the pollarding of parkland trees have usually been interpreted as the effect of ‘fertility islands’ in an environment with
strong nutrient limitations. It may well be, however, that the persistence of the tree roots plays a complementary role in supporting crop growth in these circumstances. Published estimates of the volume of water involved vary from 5% to 30% of potential daily evapotranspiration. Most publications so far indicate that hydraulic lift can mitigate, but not reverse, the drying of soil layers, postponing the emergence of water stress. Bayala et al. (2008), however, described a case where night-time re-wetting of topsoil layers exceeded daytime uptake after the harvest of a grain crop.

14.5.2 Essential and sufficient assumptions for modelling hydraulic equilibration

Current procedures for quantifying ‘hydraulic lift’ are based on the amplitude of the day–night cycle in either soil water potential or soil water content, often involving the fit of a sinusoidal relationship. At hourly, daily or weekly timescales, the mass balance for any layer of soil (i) prescribes:

$$\Delta W_s = H_{RS + R,i} - f_i \text{Uptake} + g_i \text{Rain} - h_i \text{Drain}$$  \hspace{1cm} (Eqn 14.1)

where $\Delta W_s$ is the change in soil water content, $H_{RS + R,i}$ indicates hydraulic redistribution through soil and roots, $f_i, g_i$ and $h_i$ are partitioning factors that satisfy $\Sigma f = \Sigma g = \Sigma h = 1$. The ‘rainfall’ term (Rain) includes irrigation, the balance of runoff and runoff and/or snowmelt under relevant conditions, the ‘Drain’ term both vertical and horizontal (net of outflow minus inflow) components, and ‘Uptake’ includes surface evaporation for the topsoil compartment.

In the absence of rainfall, this implies

$$H_{RS + R,i} = f_i \text{Uptake} - \Delta W_s + h_i \text{Drain}$$  \hspace{1cm} (Eqn 14.2)

Night-time hydraulic redistribution can be derived from the night-time change in soil water content only under the assumption of zero uptake, or the absence of restoring water stocks in the tree trunk. Hydraulic redistribution on a daily timescale requires assessment of the uptake term, which is non-negligible at this timescale. The ‘Drain’ term is of some interest, as it relates to the soil component of $H_{RS + R}$.

14.5.3 Hydraulic equilibration in WaNuLCAS

A more detailed account of hydraulic equilibration through the root systems of crops or trees that connect relatively dry and relatively wet zones of the soil was incorporated into the model of water, nutrient and light capture in agroforestry systems (WaNuLCAS model) (van Noordwijk et al., 2011c). The process of ‘hydraulic equilibration’ is driven by the existence of differences in water potential among the layers (and zones) of a soil profile and the availability of conductors in the form of root systems that are connected to the soil.

Implementation requires the following steps:

- Estimation of equilibrium stem base water potential at zero flux, from the root-weighted average of the soil hydraulic potential in each cell; the proportionality factor consists of root-length density and the volume of the cell as other proportionality factors cancel out in the equation.
- Derivation of the equivalent equilibrium volumetric soil water content in each cell on the basis of this stem base potential for each tree or crop type and the parameters of the pedotransfer function.
- Calculation of the amount of water involved in the difference between current and equilibrium soil water content (positive differences as ‘potential supply’ of water, negative ones as ‘demand’).
- Derivation of the potential flux as the minimum of a ‘cap’ (HydEq fraction that relates to soil transport constraints that may have to be calibrated to actual data; the HydEq fraction default value is 0.1 day$^{-1}$; for a value of 1, the model becomes
a 1-pool soil model, for a value of 0 there is no hydraulic equilibration) of the difference between the target and the actual volumetric soil water content, and a potential flux that is in accordance with the potential difference, the hydraulic conductivity of the roots, the root diameter and root length density and the period of time available (based on the fraction of day that stomata are expected to be closed).

- Reductions on either the positive or the negative potential fluxes are to be in accordance with a zero-sum net process, by calculating the minimum of the total potential supply and the total potential demand, and scaling down the cell-specific differences such that total supply matches total demand.
- Implementing the resulting flux in or out of each cell on a daily time-step basis and checking the consistency of the water balance for errors or inconsistencies.

For a 'standard' case of parklands (with parameterization for a parkland system in Burkina Faso, as simulated by Bayala et al., 2013b) the implementation leads to (Fig. 14.4):
- a total hydraulic equilibration flux through tree roots that is 64% of the tree transpiration
- slight increases for processes that depend on topsoil water content: runoff, soil evaporation
- a 9% increase in crop water uptake
- a 22% decrease of tree water uptake (and 10% decrease in canopy interception)
- a 15% decrease in vertical drainage.

These results are only moderately sensitive to the value (arbitrarily) selected for the HydEq Fraction; values above 0.2 may be unrealistic. In all situations, the tree + crop uses more water than the crop alone would have done.

### 14.6 Trees and Progressive Climate Change

Actions towards climate change adaptation, according to Vermeulen et al. (2012), fall into two broad overlapping areas:

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**Fig. 14.4.** Impacts on the water balance of a parkland system with a rainfall of approximately 750 mm year⁻¹ of the presence of trees and the inclusion of hydraulic equilibration in the model, for a range of values of the (arbitrarily set) HydEqFraction parameter.
• better management of agricultural risks associated with increasing climate variability and extreme events
• accelerated adaptation to progressive climate change over decadal timescales; for example, integrated packages of technology, agronomy and policy options for farmers and food systems.

The buffering effects of trees in agricultural landscapes as discussed here and in van Noordwijk et al. (2011a) are part of the first approach but are not mentioned explicitly by Vermeulen et al. (2012).

Many trees have a considerable adaptive range, especially the slower-growing species. Gebrekirstos et al. (2011) describe the negative relationship between tree growth rates under favourable circumstances, facilitated by sapwood with large xylem vessels, and the performance under severe drought, when small xylem vessels and dense wood are of an advantage. As the rate of climate shifts, the lateral displacement of iso-climes over the land surface, may well exceed the intergenerational rate of tree seed dispersal, except for wind-borne pioneer trees, the tolerance to climate change will determine the fate of many tree species. Tree species of recognized human use will have to be helped in reaching the parts of the world that still suit them.

Many of the most widespread agroforestry species behave like invasive exotics in places where they have been introduced and have naturalized. For such trees, climate change is not likely to be a major challenge, but for other tree species, especially in locations currently on the edge of a distribution range, it may be relevant to seek tree germplasm in ‘climate analogues’, places where the current climate resembles what can, in future, be expected for the place where the trees are to be planted. Climate change may lead to some novel climate situations, without current analogues, but its primary effect will be shifting current climates to new places, so that analogues can be found in the current situation, allowing farmer-to-farmer communication, social exchange, value chain shifts and germplasm transfer to be explored.

Analysis of tree spread in response to warming after interglacial periods, or their expansion from mountain refuges after dry and hot geological climate episodes, has shown that tree species move at individually differentiated rates, rather than as assemblages (Hewitt, 1999). The presence of a suitable soil microflora with suppression of disease organisms probably is an underrated factor in the spread of tree species to new habitats, with little predictive skill in current science. The expansion of termites to temperate regions and urban environments without frost has been noted as a challenge to trees not adapted to these rhizovores (van Noordwijk et al., 1998).

Biophysical buffering effects of trees on micro- or meso-climate, as discussed so far, will not be sufficient in the face of progressive climate change. Their interaction with the buffering of socio-economic processes related to social and human capitals will need further attention in a dynamic landscape context (Table 14.1).

14.7 Concluding Remarks

Further interdisciplinary research on the way dynamic landscapes provide buffering and other ecosystem services may benefit from a number of analytical steps to assess supply and demand, current sufficiency and trends of buffering across the multiple capitals of Table 14.1. It can, however, build on local ecological knowledge and experience in dealing with past shocks, as well as quantitative scenario studies of local socio-ecological systems and their linkages with the wider outside world.

The biggest stumbling blocks for realizing the full contributions agroforestry can make to the challenge of adapting our food production systems, multifunctional landscapes and rural livelihood systems probably still are: (i) the mindset of agricultural scientists trained to think that open-field agriculture is the norm and standard; (ii) climate scientists who have not even started serious downscaling of climate change predictions to include the effects of local land cover change on local temperature,
Table 14.1. Examples of buffering across natural (N), social (S), human (H), physical infrastructure (P) and financial (F) capital types. The letters ‘AF’ after each capital symbol refers to the contribution of agroforestry to the buffering function. IPR = intellectual property rights.

<table>
<thead>
<tr>
<th>Capital type</th>
<th>Buffer functions in the face of external variability</th>
<th>Threats to buffering/increasing buffer demand</th>
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<tbody>
<tr>
<td>N – AF</td>
<td>Protection from wave action</td>
<td>Coral reefs, coastal vegetation, mangrove</td>
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<tr>
<td></td>
<td></td>
<td>(Bayas et al., 2011)</td>
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<tr>
<td>N – AF</td>
<td>Flow buffering, protection from floods and</td>
<td>Vegetated upper watersheds, riparian zone,</td>
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<td></td>
<td>droughts, given climatic variability</td>
<td>wetlands (van Noordwijk et al., 2004b,</td>
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<td>2011b; Ma et al., 2010; Verbist et al.,</td>
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<tr>
<td></td>
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<td>2010)</td>
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<tr>
<td>N – AF</td>
<td>Protection from landslides and erosion,</td>
<td>Trees on slopes, through deep and</td>
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<td></td>
<td>given extreme rainfall events</td>
<td>superficial rooting patterns (Reubens et al.,</td>
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<td></td>
<td></td>
<td>2007)</td>
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<tr>
<td>N – AF</td>
<td>Freshwater supplies as groundwater</td>
<td>Maximize rainwater infiltration</td>
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<tr>
<td></td>
<td></td>
<td>(Hairiah et al., 2006)</td>
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<tr>
<td>N – AF</td>
<td>Nutrient supply between temporary excess and</td>
<td>Organic matter-rich soil and synchrony</td>
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<tr>
<td></td>
<td>shortage</td>
<td>management (van Noordwijk and Cadisch,</td>
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<td></td>
<td></td>
<td>2002)</td>
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<tr>
<td>N – AF</td>
<td>Limit pest and disease outbreaks</td>
<td>Biological reservoirs of control agents</td>
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<td></td>
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<td>(Jackson et al., 2012)</td>
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<td>N – AF</td>
<td>Specific response of crops and domesticated</td>
<td>Agrobiodiversity with portfolio of multiple</td>
</tr>
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<td></td>
<td>stock to abiotic and biotic variation</td>
<td>species reducing risk</td>
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<tr>
<td></td>
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<td>(Nguyen et al., 2012)</td>
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<td>N/S – AF</td>
<td>Transitions and interactions between</td>
<td>Integrated conservation and development</td>
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<td></td>
<td>‘conservation’ and ‘development’ functions</td>
<td>programmes (Minang and van Noordwijk,</td>
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<td></td>
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<td>2013)</td>
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<tr>
<td>N/S/F</td>
<td>External appreciation for local ecosystem</td>
<td>Co-investment in ecosystem services (van</td>
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<td></td>
<td>functions (ES) beyond their weight in land-use decisions</td>
<td>Noordwijk and Leimona, 2010; van</td>
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<td></td>
<td></td>
<td>Noordwijk et al., 2012)</td>
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<tr>
<td>S</td>
<td>Internal social pressures</td>
<td>Social networks within extended families</td>
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<tr>
<td>S</td>
<td>External social pressures</td>
<td>Social networks across neighbouring villages</td>
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<tr>
<td></td>
<td></td>
<td>or islands (Silvey and Elmhirst, 2003)</td>
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<tr>
<td>S – AF</td>
<td>Shifting policies on forest–community</td>
<td>Village forest, community-based forest</td>
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<td>interactions (de/re-centralization)</td>
<td>management agreements (Akiefnawati et al.,</td>
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<td></td>
<td></td>
<td>2010)</td>
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<tr>
<td>S/H</td>
<td>Response of flora and fauna to environmental</td>
<td>Local ecological knowledge (LEK), its</td>
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<td></td>
<td>variation and human management</td>
<td>accumulation and reproduction</td>
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<td>H</td>
<td>Fluctuating job opportunities</td>
<td>Education and diversification of skills</td>
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<td>within families</td>
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<td>P</td>
<td>Engineering structures in response to</td>
<td>Engineering for coastal protection, water</td>
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<td></td>
<td>earthquakes, tsunamis, sea-level</td>
<td>storage, marine + aerial transport</td>
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<td>fluctuations</td>
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<td>F</td>
<td>Fluctuations in economic markets, exchange</td>
<td>Traditional + modern savings and insurance</td>
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<td>rates and credit supply</td>
<td>systems, microcredit provision</td>
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humidity, wind speed and other parameters of direct human relevance; (iii) the makers and shapers of agricultural, forestry and land-use policies who treat forestry and agriculture as opposite sides of a coin that can only fall on either side of the institutional divide. The main supporters of the emergence of agroforestry as part of the solution are the farmers of the world who have defied the advice to oversimplify and overspecialize their farms and landscapes. Studies such as that by Nguyen et al. (2012) start to document the ways farmers perceive that trees substantially reduce their exposure to climate risk, and part of the research community is picking up this challenge – but as other chapters in this book will probably show, most of the analysis of climate change adaptation in agriculture is not thinking outside of the specialization box.

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References


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