Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Environmental Sustainability

Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa

J Bayala[1], J Sanou[2], Z Teklehaimanot[3], A Kalinganire[1] and SJ Ouédraogo[4]

In the Sahelian zone of West Africa, crops grown under a discontinuous cover of scattered trees dominate many landscapes and constitute the so-called parklands. These systems reflect the ecological knowledge of the farmers of such risk prone environments. Agroforestry parklands are playing an important role, through trees and shrubs providing soil cover that reduces erosion and buffers the impacts of climate change. They also provide green fodder that complements crop residues for livestock feeds, and fruits and leaves for human consumption and for income generation. The interactions between various components of the system influence the ecosystem service functions of trees of parklands (provisioning, regulating and supporting services) in several ways. These ecosystem functions have been at the center of the local ecological knowledge guiding the management options of the farmers and have also attracted the attention of scientists. Findings revealed new challenges that call for production options ensuring increased and diversified productivity of the systems while preserving the environment. Research on such challenges must adopt an inclusive approach based on local knowledge supported by science-based analyses of the socio-ecological systems in the face of high population pressure and climate change.

Addresses
[1] World Agroforestry Centre (ICRAF), ICRAF-WCA/Sahel, BP E5118 Bamako, Mali
[2] Institut de l'Environnement et de Recherches Agricoles, Département Productions Forestières, 03 BP 7047 Ouagadougou 03, Burkina Faso
[3] School of Environment, Natural Resources and Geography, Bangor University, Bangor, Gwynedd LLL57 2UW, UK
[4] Institut du Sahel (INSAH), BP 1530 Bamako, Mali

Corresponding author: Bayala, J (j.bayala@cgiar.org, BayalaJ2013@gmail.com)

Current Opinion in Environmental Sustainability 2014, **6**:28–34

This review comes from a themed issue on **Sustainability challenges**

Edited by **Cheikh Mbow**, **Henry Neufeldt**, **Peter Akong Minang**, **Eike Luedeling** and **Godwin Kowero**

For a complete overview see the Issue and the Editorial

Received 27 May 2013; Accepted 11 October 2013

Available online 1st November 2013

1877-3435/$ – see front matter,

http://dx.doi.org/10.1016/j.cosust.2013.10.004

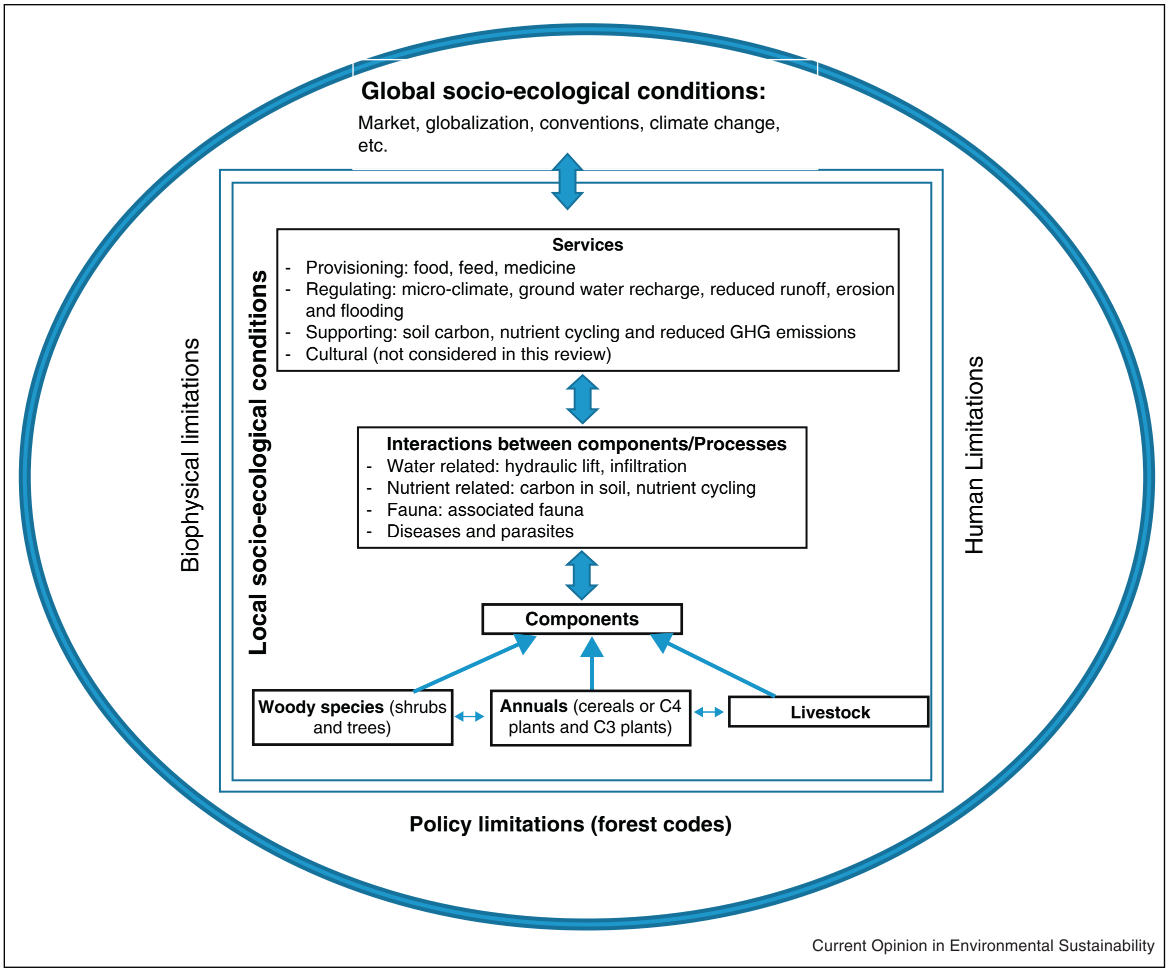
Introduction

The farming systems in the Sahel which combine trees, crops and livestock reflect strategies developed by the farmers for generations to reduce their vulnerability to risks related to climate [1,2•]. Therefore, the composition of the tree component of these systems results from a careful selection over the generations resulting in what are called agroforestry parklands [3•,4••]. Although parklands occur in other areas of the world, such as Southern Africa and the Mediterranean, it is here in semi-arid West Africa that these agroforestry systems are most widespread [5•]. Parklands generally incorporate several agroforestry tree species and genera that constitute important sources of firewood, medicine, food and nutrition [6,7]. But changing circumstances (climatic, political, among others) are threatening the efficacy and sustainability of these systems due to livestock pressure on seedlings that reduces natural regeneration, shortened periods of fallow and severe tree lopping for feed requirements and firewood supply [8••]. In this context, rehabilitation of the degraded systems should be based on a sound understanding of their ecological functions and drivers of their degradation to develop relevant solutions. The present paper is a synthesis of the ecosystem functions resulting from interactions between various components of the parklands (Figure 1). More specifically the paper focuses on the effects of parkland systems on food production and climate change in the Sahel. Compilation of data on parkland practices was made from all available information, peer-reviewed, and non-peer-reviewed research papers produced from well designed and replicated experiments and observational studies on either research stations or on farmers' fields. The screening of such studies was made primarily by accessing various electronic databases. Specific sources included databases maintained by World Agroforestry Centre (ICRAF), United Nations Food and Agriculture Organization (FAO), and Google Scholar. The searches for 'grey' literature such as student theses and unpublished research reports is certainly incomplete due to its accessibility that may require travelling to the various locations where the documents are stored.

Complexity of the parklands

Parklands in the Sahel are formed of selected trees and shrubs from the original natural woodland after clearing for cropping and as a result, they are dominated by a few favored species such as *Faidherbia albida*, *Parkia biglobosa*, and *Vitellaria paradoxa* [3•,7,10]. The number of preserved species has been reported to range from 20 to 110 species in the Sahel [9,10]. Tree density varies but is typically maintained at less than 20 per hectare, and farmers plant staple cereal crops (millet, sorghum and maize) together with legumes such as cowpea or rotated

Figure 1



Ecosystems services emanating from the interactions between components of the parkland systems.

with groundnut for replenishment of soil nitrogen and for product diversification. Livestock feed on crop residues and the leaves and pods of fodder tree species and deposit manure in the fields, thus helping nutrient recycling. Besides trees, parklands also contain shrubs that are repeatedly coppiced when preparing land for growing agricultural crops. Although they have been less studied than the trees, shrubs contribute to the complexity of the production systems with regard to the interactions between various components. Some parklands are mono-specific (e.g. *F. albida* and *Borassus aethiopum* based parklands), but others have some dominant tree species mixed with a range of other tree and shrub species, making the studies of tree–crop–livestock interactions extremely complex.

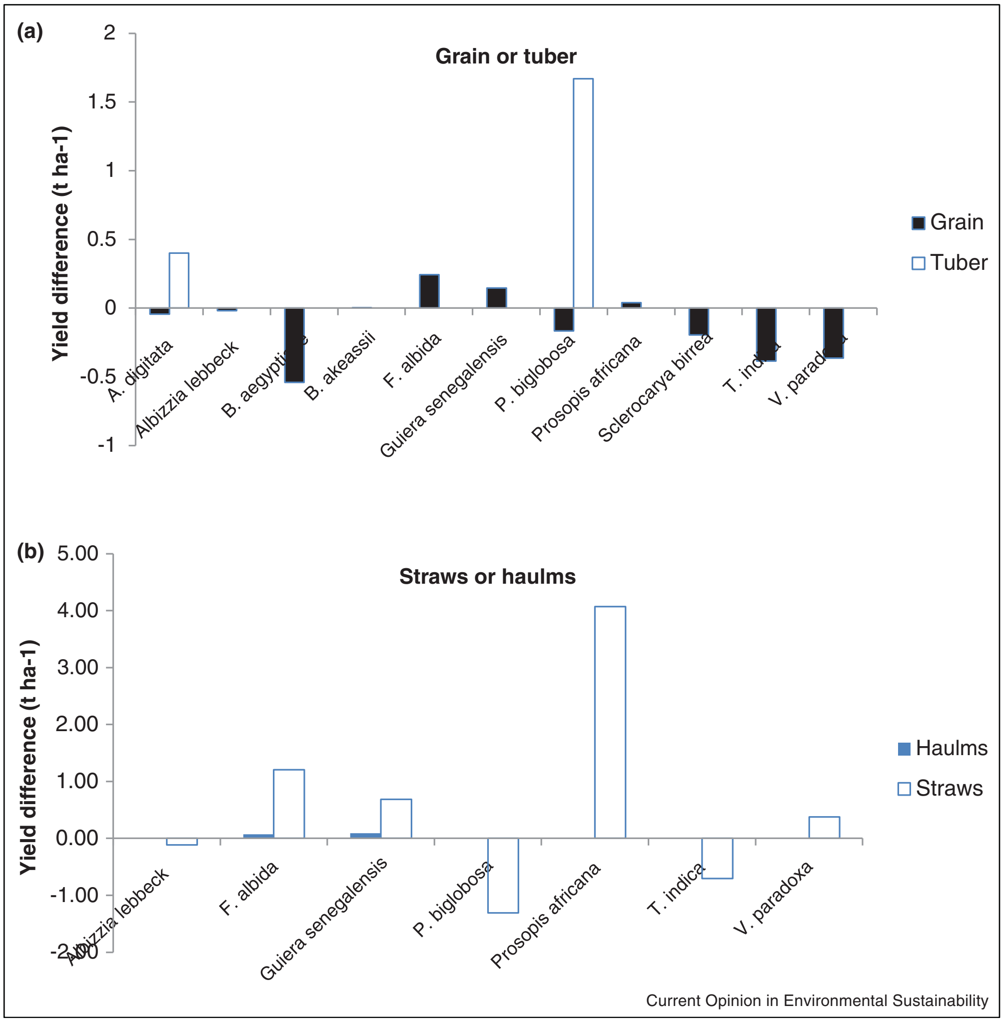
Ecosystems services provided by the parklands

Ecosystem services are reported as the benefits people obtain from ecosystems (MEA) [11,12]. They are further divided into four broad categories: provisioning services (food, fuel wood, fiber, biochemical, and genetic resources); regulating services (climate, diseases, water regulation and purification); supporting services (soil formation, nutrient cycling, primary production and provision of habitat); and cultural services (recreational and ecotourism, aesthetic, inspirational, educational, sense of place and cultural heritage). The interactions between various components influence the ecosystem service functions of agroforestry parkland systems in several ways, and these are described in the following sections. However, the cultural services as well as the economic aspects of the parklands are not included in this review as the focus of this paper is about food security.

Provisioning services

As cereals are the most common staple crops associated with trees in the Sahelian parklands, many studies have focused on tree-cereal combinations. Studies on tree–crop interactions have clearly shown that trees have highly

Figure 2



Variability in crop responses according to tree species in parkland systems when comparing the yield in the influence zone trees with that of a treeless monoculture control plot in the Sahel: grain and straws for cereals of *Pennisetum glaucum*, *Sorghum bicolor*, and *Zea mays*; tuber of *Colocassia esculenta*, haulms of *Arachis hypogea* (Nb of references 19 giving 69 pairs for grain, 3 pairs for Tuber, 13 pairs for haulms and 32 pairs for straws). The yield difference was defined as the difference in grain or straw dry matter yield between crops grown under a given species of parkland system and the control of no such practice (open treeless area or control plot) from the same study.

varying effects on the associated crops when comparing the yield of associated crops in the influence zone of trees with that of a treeless monoculture control plot (Figure 2). Cereal (C_4 plant) grain yield difference was found to be varying from -0.54 t ha^{-1} under *Balanites aegyptiaca* to +0.24 t ha^{-1} under *F. albida* and biomass yield difference from -1.31 t ha^{-1} under *P. biglobosa* to +4.07 t ha^{-1} under *Prosopis africana*. Legumes (cowpea and groundnut) seem to be less affected by tree cover while tuber (*Colocasia esculenta*) yield is rather improved under trees compared to the treeless monoculture plot of the same crop (+0.40 to +1.67 t ha^{-1}). Both legumes and tubers are C_3 plants expected to show greater shade tolerance than the C_4 plants. Patterns for cereals are in line with the meta-analysis results of Bayala *et al.* [13]. The observed yield reductions for cereals have been attributed to competition for light, nutrients and water [14••,15–19].

Tree-crop competition may be reduced by tree management practices such as crown pruning [15] and root pruning [16] and by use of shade tolerant crops [17–19]. Crown pruning was reported to help rejuvenate old poorly fruiting individuals while improving associated cereal yield under *P. biglobosa* and *V. paradoxa* [20].

Tree fruits and other edible tree products constitute an important source of micro-nutrients and vitamins that complement the cereal-based diet of the Sahelian population. On the basis of a household survey, the quantity of tree products (fruits of *Lannea microcarpa*, *P. biglobosa*, *Saba senegalensis*, *V. paradoxa*, among others) consumed per day was found to be equivalent to varying percentages of the human body daily requirements for nutrients: 0.4–18.8% for energy, 0.3–11.6% for proteins, 0–2.3% for lipids, 0.7–80.1% for calcium and 0.6–68.7% for iron [21]. Trees also make up a large proportion of high quality fodder intake by livestock, and tree fodder is crucial in the dry season as well as during periods of drought [22].

Regulating services

Jonsson *et al.* [23] reported that agricultural crops under trees were less exposed to excessive temperatures of above 40 °C with 1–9 h week^{-1} under *V. paradoxa* and *P. biglobosa* against 27 h week^{-1} in the open field. Longer thermal time, a summation of cumulative differences between daily mean temperatures, was recorded under both *V. paradoxa* (19 °C d) and *P. biglobosa* (18 °C d) compared to the open area (2 °C d). The mean temperature was 29 °C under a small *V. paradoxa* tree which is not significantly different from the 30 °C in the open, whereas the temperature was lower under *P. biglobosa* (27 °C). Similarly, Bayala *et al.* [24] reported a reduction of the maximum daily temperature by an average of 1–2.5 °C and an increase of the minimum air humidity by up to 5%, with stronger differences on hotter and drier days. Trees can also reduce wind speed while increasing soil and air humidity as well as diseases like fungal attacks. Depending on the conditions, they can also deplete soil water, reduce air humidity and diseases by discontinuing their favorable habitat [25,26]. Reduction in radiation affects the photosynthesis of C_4 species more severely than that of C_3 species [18,19,27,28]. Rain water can be lost due to canopy interception, but higher amount of rain (throughfall + stemflow) can also be collected under trees and that depends on tree species and their canopy shape. Rainfall interception was about 22% by *Cordyla pinnata* [29]. All these changes in microclimate are species-specific and management-specific due to differences in height, crown density and shape [17].

For soil properties, recent studies of Sahelian agroforestry parklands have revealed a decrease in soil bulk density and as a consequence, soils under trees displayed higher porosity compared to adjacent open areas [30–32]. Thus, infiltration capacity (IC) under *V. paradoxa* and *F. albida* was higher (104 mm h^{-1}) than in nearby treeless areas (69 mm h^{-1}) [30]. Higher infiltration may explain why Yaméogo [33] recorded soil water content of 8.36% in treeless area compared to 9.18% under *Borassus flabellifer* during three consecutive years. Similar trends were reported in a synthesis produced by Bayala and Ouedraogo [34] indicating that higher soil water content under trees is related to lower rates of soil evaporation, reduced soil temperatures and increased rain water, relative to treeless areas, reaching beneath trees because of canopy interception.

Another mechanism through which tree impacts soil water dynamics is what is known as hydraulic lift or hydraulic redistribution (HR) as the water movement can be downwards or lateral [35]. Bayala *et al.* [36] found that the volume of water redistributed from deeper to shallower soil layers through this mechanism represented 18–20% of the quantity transpired by *P. biglobosa* and *V. paradoxa*. The magnitude of HR in *Guiera senegalensis* and *Piliostigma reticulatum* in Senegal ranged between 15% and 42% of the daily soil water depletion in the 20 cm upper soil layers [37]. Dimorphic root systems of *F. albida* allow this species to tap groundwater at large depths suggesting the existence of HR in this species [38]. Hydraulic redistribution may be an important mechanism for drought stress avoidance while maintaining plant physiological functions in both woody and neighboring annuals in water-limited environments [36,37].

Supporting services

Trees in the parklands contribute to the reduction of carbon in the atmosphere by accumulating biomass via photosynthesis. This process is important in improving soil properties when the accumulated biomass is stored in the below-ground compartment as soil carbon. However, increase in soil fertility parameters by trees has been seen as a controversial issue because trees may have simply grown in spots of higher fertility. Therefore, studies were carried out to elucidate this point by separating the contribution of trees from that of other components (crops and weeds) using ^{13}C natural abundance method. Thus, Jonsson [39] found the C_3-species derived carbon contribution to be 30% higher in the soil under *P. biglobosa* than in adjacent treeless areas. Similarly, Bayala *et al.* [40] found higher soil carbon contents under *P. biglobosa* and *V. paradoxa* than in the open area and these differences were fully explained by the C_3 (trees) contributions. Evaluating the C stocks of various agroforestry systems, Takimoto *et al.* [41] found biomass C stocks ranging from 0.7 to 54.0 Mg C ha^{-1}, and total C stock (biomass C and soil C) from 28.7 to 87.3 Mg C ha^{-1}. Estimates at peak-season of C stock ranged from 0.9 to 1.4 Mg C ha^{-1} in *G. senegalensis* and from 1.3 to 2.0 Mg C ha^{-1} for *P. reticulatum* [42]. The overall mean soil organic carbon to 40 cm soil depth was about 17 Mg C ha^{-1} for both species with 57% of that residing in the upper 20 cm soil layer. In such systems, returning prunings of the two shrubs for 50 years, instead of burning them as currently practiced, would increase soil C sequestration by 200–350% without fertilization, and increase soil C sequestration by 270–483% under a low fertilization regime [42]. That would make these systems become sinks rather than sources of emissions [42].

Various studies have assessed fine roots in parklands and quantified leaf litter fall and litter decomposition [34,42]. Because of root and litter inputs and nitrogen fixed by legumes, higher soil nitrogen content has been found under parkland trees by many authors [17–19,25,30]. Other potential sources of soil fertility improvement are faeces of birds resting and nesting on trees, and faeces and urine of animal resting under trees, deposition of organic dust, among others [34].

All these results show that trees/shrubs in agroforestry parkland systems have a direct positive contribution to soil carbon content, justifying the need to encourage the maintenance of trees on farmed lands in semi-arid environments where carbon content of soil appears to be the key limiting factor for crop growth and production [34,43].

Discussion and conclusions

In addition to the recognized contribution of trees to microclimate modification, soil fertility improvement seems be an accepted effect of trees in parklands [39,40]. However, controversy still exists as to whether trees really contribute to soil fertility or redistribute it. In situations where trees are simply recycling pre-existing fertility, the production system as a whole gains nothing but trees help preserve this fertility which otherwise will be rapidly depleted. In addition, the use of isotopes helped disentangle the relative contributions of trees and annual crops to soil carbon revealing the important role of trees in preserving and sustaining favorable soil conditions for the production of staple crops [25,42,43]. Indeed, in the Sahel, Cation Exchange Capacity (CEC) strongly depends on the presence of organic carbon which has a positive impact on soil fertility. Trees have been reported having a positive impact on CEC [34]. As a consequence, agroforestry is nowadays widely acknowledged as a valuable land management option under various concepts including evergreen agriculture and climate smart agriculture [44••].

Despite the above positive impact of trees, it has been widely reported that trees and crops compete for growth resources. The above-ground competition is related to light, heat, air relative humidity, wind speed and rain interception [21,27]. The below-ground competition is for water and nutrients, and it is generally expected that the roots of trees and crops occupy different soil layers, at least to some extent [4••,45]. Field data have shown an overlap of roots of both plant types, thus exacerbating the severity of below-ground competition [14••]. However, such relationships between components may be either of competition or of facilitation types.

Indeed, whether competition or facilitation is taking place, depends on the species and the ecological context. *F. albida*, with a reverse phenology, has been reported to stimulate crop yield, particularly cereals grown in the Sahel, which are C_4 plants. Similarly, species with a canopy allowing some light to reach underneath (*A. digitata*, *Borassus* spp., *Hyphaene thebaica*) even in leaf can still positively impact cereal production [27,33]. When the leafing periods of both crop and tree coincide, there is competition for light for which C_4 plants are more affected than the C_3 crops [27,28]. The results of a meta-analysis revealed that parkland effects tend to be positive on cereals where annual average rainfall was lower than 800 mm and on sites where yields of the control plots (without trees) were less than 2 t ha^{-1} [13].

Because competition seems to be prevalent in the relationships between the woody (trees and shrubs) and the agricultural crop (cereals) components, a range of parkland management options have been tested. Woody species composition, density and growing certain crops under heavy shade as applied by farmers are rather intuitive and empirical. To support the local ecological knowledge, experimental testing of replacing cereals by shade tolerant crops has indicated potential benefits [17–19]. Similarly, pruning as a management tool has also been successful in increasing cereal yields [14••,15]. However, trees are traditionally maintained in croplands for many purposes in addition to sustaining cereal yields. A range of products is generated from trees and system evaluations have shown that in some cases fruit production compensated for the loss in cereal production [20].

We conclude that there is a need for a more comprehensive analysis of the multiple benefits and services provided by parkland trees [13]. The scientific understandings already achieved, and summarized in this paper, need to be applied to improve farming livelihoods in the low-productivity agro-ecological conditions of the Sahel.

Acknowledgements

This research area of ICRAF is financed by the CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS). We thank Dr. Chris Harwood of CSIRO for proof reading the draft for the English.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cosust.2013.10.004.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Food Agriculture Organization (FAO): *Disaster Risk Management Strategy in West Africa and the Sahel FAO (2011–2013)*. Rome, Italy: FAO; 2011, .

2. • Neufeldt H, Dawson IK, Luedeling E, Ajayi OC, Beedy T, Gebrekirstos A, Jamnadas RH, König K, Sileshi GW, Simelton E, Montes CS, Weber JC (Eds): *Climate change vulnerability of agroforestry. ICRAF Working Paper No. 143*. Nairobi: World Agroforestry Centre; 2012.

This meta-analysis focused on 10 tree species' functions in relation to their vulnerability by searching and summarizing the information from online databases that provides data on about 650 species from six regions worldwide that can be planted or harvested in the wild.

3. Boffa JM (Ed): *Agroforestry Parklands in Sub-Saharan Africa*.
• Rome, Italy: FAO Conservation Guide; 1999.

This book is the most detailed synthesis of the existing knowledge on parkland systems and may need to be updated as since its release fourteen years back new knowledge has been produced.

4. van Noordwijk M, Ong CK: **Can the ecosystem mimic**
•• **hypotheses be applied to farms in African savannahs?** *Agrofor Syst* 1999, **45**:131-158.

This article tested the ecosystem mimic hypotheses for parklands and revealed that the hypothesis may be valid if tree density increases and trees meet criteria making them less competitive for growth resources or if the components of the system yield products/services of similar socio-economic importance for the local people.

5. Zomer RJ, Trabucco A, Coe R, Place F: **Trees on farm: analysis of**
• **global extent and geographical patterns of agroforestry**. *Working Paper No. 89*. Nairobi, Kenya: The World Agroforestry Centre; 2009, .

This analysis indicated that 46% of land classified as agricultural, globally, contains at least 10% tree cover. From such lands about 30% have tree cover that qualifies them as a forest.

6. Faye MD, Weber JC, Mounkoro B, Dakouo J-M: **Contribution of parkland trees to village livelihoods – a case study from Mali**. *Dev Pract* 2010, **20**:428-434.

7. Faye MD, Weber JC, Abasse TA, Boureima M, Larwanou M, Bationo AB, Diallo BO, Sigué H, Dakouo J-M, Samaké O, Sonogo-Diaité D: **Farmers' preferences for tree functions and species in the West African Sahel**. *For Trees Livelihoods* 2011, **20**:113-136.

8. Gonzalez P, Tucker CJ, Sy H: **Tree density and species decline**
•• **in the African Sahel attribute to climate**. *J Arid Environ* 2012, **78**:55-64.

This paper attempted to disentangle the contribution of various factors to the observed tree density decrease in the Sahel and found a dominance of temperature and precipitations, supporting the hypothesis that tree cover changes can be attributed to climate variability.

9. Kindt R, Kalinganire A, Larwanou M, Belem M, Dakouo JM, Bayala J, Kaire M: **Species accumulation within land use and tree diameter categories in Burkina Faso, Mali, Niger and Senegal**. *Biodivers Conserv* 2008, **17**:1883-1905.

10. Bayala J, Kindt R, Belem M, Kalinganire A: **Factors affecting the dynamics of Tree diversity in agroforestry Parklands for cereal and cotton farming system in Burkina Faso**. *New Forest* 2011, **41**:280-296.

11. MEA: *Millennium Ecosystem Assessment. Ecosystems and Human Well-Being Synthesis*. Washington, DC: World Resources Institute; 2005, .

12. Power AG: **Ecosystem services and agriculture: tradeoffs and synergies**. *Philos Trans R Soc Lond B Biol Sci* 2010, **365**:2959-2971.

13. Bayala J, Sileshi GW, Coe R, Kalinganire A, Tchoundjeu Z, Sinclair F, Garrity D: **Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis**. *J Arid Environ* 2012, **78**:13-25.

14. Bayala J, van Noordwijk M, Lusiana B, Kasanah N,
•• Teklehaimanot Z, Ouedraogo SJ: **Separating the tree–soil–crop interactions in agroforestry parkland systems in Saponé (Burkina Faso) using WaNuLCAS**. *Adv Agroforestry* 2008, **4**:296-308.

This is one of the first studies combining a manipulative field trial with modeling to better understand the interactions in parkland systems, particularly the most limiting factors for the associated crops.

15. Bazié HR, Bayala J, Zombré G, Sanou J, Ilstedt U: **Separating competition-related factors limiting crop performance in an agroforestry parkland system in Burkina Faso**. *Agrofor Syst* 2012, **84**:377-388.

16. Bayala J, Bazié HR, Sanou J: **Competition and facilitation-related factors impacts on crop performance in an agroforestry parkland systems in Burkina Faso**. *Afr J Agric Res* 2013. (in press).

17. Sanou J (Ed): *Optimizing Productivity of Agroforestry Parkland Systems in West Africa Using Shade Tolerant Annual Crops*. Bangor, UK: University of Wales; 2010.

18. Sidibé D (Ed): *Improving the management and productivity of Ziziphus mauritiana and Tamarindus indica in agroforestry parkland systems in Mali, West Africa*. UK: School of Environment, Natural Resources and Geography, Bangor University; 2010. PhD thesis.

19. Pouliot M, Bayala J, Ræbild A: **Testing the shade tolerance of selected crops under *Parkia biglobosa* (Jacq.) Benth. in an agroforestry parkland in Burkina Faso, West Africa**. *Agrofor Syst* 2012, **85**:477-488.

20. Bayala J, Ouedraogo SJ, Teklehaimanot Z: **Rejuvenating indigenous trees in agroforestry parkland systems for better fruit production using crown pruning**. *Agrofor Syst* 2008, **72**:187-194.

21. Parkouda C, Diawara B, Ganou L, Lamien N: **Potentialités nutritionnelles des produits de 16 espèces fruitières locales**. *Sci Techn Sci Appl Technol* 2007, **1**:35-47.

22. Hansen HH, Sanou L, Nacoulma BMI: **Tree leaves in the diet of free-ranging ruminants in three areas of Burkina Faso**. *Livestock Res Rural Dev (in print)* 2008, **20** http://www.cipav.org.co/lrrd/.

23. Jonsson K, Ong CK, Odongos JC: **Influence of scattered néré and karité on microclimate, soil fertility and millet yield in Burkina Faso**. *Exp Agric* 1999, **35**:39-53.

24. Bayala J, Sanou J, Bazié P, van Noordwijk M: *Empirical data collection of tree effects on temperature and humidity at crop level. CRP 7 Activity Report*. Nairobi: World Agroforestry Centre; 2013, .

25. Brenner AJ: **Microclimatic modifications in agroforestry**. In *Tree–Crop Interactions: A Physiological Approach*, 1996. Edited by Ong CK, Huxley P. UK: CAB International; 1996:159-187.

26. Schroth G, Krauss U, Gasparotto L, Duarte Aguilar JA, Vohland K:: **Pests and diseases in agroforestry systems of the humid tropics**. *Agrofor Syst* 2000, **50**:199-241.

27. Sanou J, Bayala J, Teklehaimanot Z, Bazie P: **Effect of shading by baobab (*Adansonia digitata*) and néré (*Parkia biglobosa*) on yields of millet (*Pennisetum glaucum*) and taro (*Colocasia esculenta*) in parkland systems in Burkina Faso, West Africa**. *Agrofor Syst* 2012, **85**:431-441.

28. Sanou J, Bayala J, Bazié P, Teklehaimanot Z: **Photosynthesis and biomass production by millet (*Pennisetum glaucum*) and taro (*Colocasia esculenta*) grown under baobab (*Adansonia digitata*) and néré (*Parkia biglobosa*) in an agroforestry parkland system of Burkina Faso (West Africa)**. *Exp Agric* 2012, **48**:283-300.

29. Samba SAN (Ed): *Influence de Cordyla pinnata sur la fertilité d'un sol ferrugineux tropical et sur le mil et l'arachide dans un système agroforestier traditionnel au Sénégal*. Québec, Canada: Faculté de Foresterie et de Géomatique, Université Laval; 1997. Thèse de Ph.D.

30. Hansson L (Ed): *Comparisons of Infiltration Capacities in Different Parklands and Farming Systems of Semi-arid Burkina Faso*. Sweden: Swedish University of Agricultural Sciences, Department of Forest Ecology; 2006. MSc thesis.

31. Zomboudré G (Ed): *Caractérisation biophysique et incidence des parcs à Vitellaria paradoxa Gaertn. et Faidherbia albida (Del.) A. Chev. Sur les facteurs pédoclimatiques et la productivité du maïs (Zea mays L.) dans la zone ouest du Burkina Faso*. Burkina Faso: Université de Ouagadougou; 2009. Thèse Doctorat Unique.

32. Sanou J, Zougmoré R, Bayala J, Teklehaimanot Z: **Soil infiltrability and water content as affected by Baobab (*Adansonia digitata* L.) and Néré (*Parkia biglobosa* (Jacq.) Benth.) trees in farmed parklands of West Africa**. *Soil Use Manage* 2010, **26**:75-81.

33. Yaméogo J (Ed): *Contribution des parcs à Borassus akeasii Bayton, Ouédraogo et Guinko au fonctionnement des systèmes de productions dans le sud-ouest du Burkina Faso*. Burkina Faso: Université de Ouagadougou; 2008. Thèse Unique.

34. Bayala J, Ouedraogo SJ: **Agroforestry and soil fertility maintenance**. In *Synthesis of Soil, Water and Nutrient Management Research in the Volta Basin.* Edited by Bationo A, Tabo R, Waswa BS, Okeyo J, Fosu M, Kabore S. Ecomedia Ltd.; 2008:41-46.

35. Burgess SSO, Adams MA, Turner NC, Ong CK: **The redistribution of soil water by tree root systems**. *Oecologia* 1998, **115**:306-311.

36. Bayala J, Heng LK, van Noordwijk M, Ouedraogo SJ: **Hydraulic Lift study in two native tree species of agroforestry parklands of West African dry savanna**. *Acta Oecolgia* 2008, **34**:370-378.

37. Kizito F, Dragila MI, Sene M, Brooks JR, Meinzer FC, Diedhiou I, Diouf M, Lufafa A, Dick RP, Selker J, Cuena R: **Hydraulic redistribution by two semi-arid shrub species: implications for Sahelian agro-ecosystems**. *J Arid Environ* 2012, **83**:69-77.

38. Roupsard O, Ferh A, Granier A, Pallo F, Depommier D, Mallet B, Joly HJ, Dreyer E: **Reverse phenology and dry-season water uptake by *Faidherbia albida* (Del.) A Chev. in a agroforestry parkland of Sudanese West Africa**. *Funct Ecol* 1999, **13**:450-472.

39. Jonsson K: *Agroforestry in Dry Savanna Areas in Africa: Interactions Between Trees, Soils and Crops*. Umea, Sweden: Swedish University of Agricultural Sciences; 1995, :. Ph.D. Dissertation.

40. Bayala J, Balesdent J, Marol C, Zapata F, Teklehaimanot Z, Ouedraogo SJ: **Relative contribution of trees and crops to soil carbon content in a parkland system in Burkina Faso using variations in natural 13C abundance**. *Nutr Cycl Agroecosys* 2006, **76**:193-201.

41. Takimoto A, Nair PKR, Nair VD: **Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel**. *Agric Ecosyst Environ* 2008, **125**:159-166.

42. Lufafa A, Diedhiou I, Samaba SAN, Séné M, Khouma M, Kizito F, Dick RP, Dossa E, Noller JS: **Carbon stocks and patterns in native shrub communities of Senegal's Peanut Basin**. *Geoderma* 2008, **146**:75-82.

43. Bationo A, Buerkert A: **Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa**. *Nutr Cycl Agroecosys* 2001, **61**:131-142.

44. •• Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A, Larwanou M, Bayala J: **Evergreen agriculture: a robust approach to sustainable food security in Africa**. *Food Sec* 2010, **2**:197-214.

This article reviewed experiences of farmers of various regions of Africa who are transforming simplified landscapes as advised by agronomists to farms with more trees, and analyses the broader implications of such transformation for African food security and environmental resilience.

45. Cannell MGR, van Noordwijk M, Ong CK: **The central hypothesis: the tree must acquire resources that the crop would not otherwise acquire**. *Agrofor Syst* 1999, **6**:27-30.