Ecosystem Services of Multispecific and Multistratified Cropping Systems

Serge Valet and Harry Ozier-Lafontaine

Abstract New cropping alternatives are explored in response to the drawbacks of the Green Revolution. Alternative practices use the ecological regulations of agroecosystems, and strengthen and manage agricultural biodiversity. Multi-species cropping systems are good models to seek innovative solutions. Indeed the combination of crops, ranging from simplest forms to complex multi-stage associations, such as agroforests, have allowed many populations to maintain their production conditions, while at the same time overcoming severe shocks such as droughts, epidemics or changes in market prices. An empirical agroecology has thus been created mainly using traditional knowledge. We present the following benefits provided by the ecosystem services of mixed cropping: (1) yields are often higher than in monocultures, (2) the amount of mineral and organic fertilizers is decreased two times, (3) mixed cropping is an effective alternative to pesticides, (4) water and energy is saved, (5) soil quality is preserved, and (6) worktime is better managed. A true agroecological engineering approach, linking scientific and empirical knowledge can thus be designed.

Keywords Agroecology • Agroecological engineering • Ecosystem Services • Multispecies systems • Multi-stratified agroforests • Peasant agriculture • Traditional knowledge

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Introduction

'*Agronomists have been trained to eradicate ecosystems in order to create an artificial system, simplified and forced by the introduction of a great quantity of fertilizers and pesticides*' Griffon (2006). Climate change, demographic pressure, environmental impacts generated by intensive agriculture -increased erosion, soil, water and human pollution, reduced biodiversity, emission of greenhouse gases -, depletion of fossil fuels and phosphate, rise in fertilizers prices, multinational and "*globalization*" speculation on food products and lands, all this creates a new context which requires a calling into question of the conventional model of agricultural production with high rates of synthetic farm inputs. The admission of failure to enhance food crops monoculture has been highlighted by the overall decline of production conditions such as the collapse of biological and physicochemical components of soil fertility, and of food crop productivity (FAO 2011), made worse by environmental impacts. In response, more and more agronomists agree that *"the reality of the difficulties encountered by the productivist projects born from the green revolution, must force us to consider this perspective as a utopia"*. That is why the Kyoto Protocol recommends the promotion of sustainable conditions for rational agriculture. Recent years have seen renewed interest for the study of mixed cropping in view of the acknowledgement, widely shared, that the conventional specialized farming model has failed (Debar 2013). Mixed-cropping practices are thus well developed in all continents, in contrasted climates, latitudes, altitudes and ecosystems, oasis, sahel, sudan and tropic (Plates 1 and 2). They come in various forms, not only bi or multi-stratified, but also multistage (Baldy 1963; Klee 1980; Brokensha et al. 1980; Mandal et al. 1990; Morelli 2003; Camara et al. 2009, 2010; Camara 2007) (Plates 1 and 2).

They are common across most agrarian civilizations and are representative of agricultural, food, fruit, forest, and industrial production systems still practiced by hundreds millions of farmers (Altieri et al. 1978; Augusseau et al. 2006; Baldy 1963; Charreau and Vidal 1965; Dupriez 1980a, 2006; Eden 1980; Fortmann and Rocheleau 1985; Hullugale 1988; Le Courrier 2002; Li et al. 2007; Malézieux et al. 2001, 2009; Mazoyer 1972; Mbomda 1985; Norman et al. 1984; Okigbo and Greenland 1976; Torquebiau and Penot 2006; Ravignan 1969; Valet 1968, 1974a, b, 1976; Valet and Motelica-Heino 2010).

The cultivated plant species and varieties, as well as their number, vary according to the latitude but also to the altitude, the food habits and the fertility of the soils (Autfray 1985; Ravignan 1969; Valet 1968, 1976). Intercropping contributes significantly to the world food production in North and South America, in Oceania and in Asia. In Africa, it accounts for the largest share in food production which is yielded in association with fodder, fruits and trees (Altieri 1999; Anil et al. 1998; Denevan 1980; Francis 1986; Lithourgidis et al. 2011; Tremblay 2006; Vandermeer 1989).

Having acknowledged the fact that traditional communities could not afford *'risking their own existence with an unbalanced use of their land'* (Dupriez 1980b), many agronomists now consider renewing traditional farming practices to promote the principles of an ecological intensification based on the supply of ecosystemic services (Gliesmann 2001; Griffon 2006; Malézieux and Moustier 2005; Malézieux et al. 2009).

Restoring on-farm biodiversity through diversified farming systems that mimic nature, is considered to be a key strategy for sustainable agriculture (Doré et al. 2006; Jackson et al. 2010). Besides, it has been shown that intensive modern techniques, even the least degrading, are seldom more profitable than mixed cropping, particularly with the sharp increase in the cost of energy, fertilizers, and machines (Jolliffe 1997; Le Buannec 1979; Roose 1983; Valet 2011a; Willey 1979).

Both Dupriez (since 1980) and Hallé (since 2010) have emphasized the multi-functional role of multi-species and multi-terraced intercropping along with successions of species and complementary varieties, useful to human and animal feeding, as well as to industrial and energetic practices (FAO 2011). Most of them are in a position to supply ecosystemic services and build up complex production systems which should be better known and developed. These ecosystem services and the scales (field, landscape, region) from which they would be assessed, have not been sufficiently taken into consideration, studied or conceptualized (Baldy and Stigter 1997; Valet 2007), compared to the volume of research projects aimed at intensive monoculture performances (Altieri 1999).

Studies on mixed-cropping agrosystems for the promotion of ecological development were carried out on a very short period in the 1960s to be undertaken again at the end of the twentieth century (Baldy 1963; Valet 1968; Malézieux et al. 2009). In their review concerning multi-species systems, Malézieux et al. (2009) propose a highly comprehensive generic framework of concepts, tools and methods available for understanding and modeling the operation and management of these systems. However, this synthesis tackles, to a lesser extent, other types of predictive approaches based on the conditions of implementation of the multi-species systems according to soil-climate and land contexts and realities and of the principles which establish the concept of '*innovative traditional ecological intensification*' introduced as early as the 1950s by the farmers. Few researchers have been interested in the processes of small-scale farming innovation (Dugué et al. 2006) concerning the eco-agroforestry and sylvo-pastoral systems so eagerly sought after by agronomists (Baldy and Stigter 1997; Dupriez 1980a; Ducret and Granget 1986; GRET 1982; Léger-Cresson 1989; Tajuddin 1986; Valet 1968, 1974a, b, 1976). This is probably related to the paradigm conveyed by modern technology and widely introduced according to the top-down model in which the mismatch between research findings and farmers' real needs on the ground is strongly enhanced (FAO 2010).

The diversity, of multispecies cropping at the field as well as well as at the hillslope scale, requires further analysis to qualify and quantify their possible contribution to the supply of ecosystem (Millenium Ecosystem Assessment 2005) and economic services which are an essential prerequisite for sustainable development. So here we review the diversity of traditional plant communities and bio physico-chemical processes that 'traditional, empirical and innovative ecological intensification' involves. This analysis covers three main areas: (1) diversity and typology of multi-species and multi-terraced intercropping at the field, landscape and territory scale, (2) ecosystem and economic services, (3) considerations on agroecological engineering of mixed/inter cropping systems.

Multi-species Cropping Systems Diversity

Mixed cropping systems cover many modes of spatial distribution – on the surface, above and below the ground level -, and time distribution, in relay with perennial or annual species. They can combine very different plants (grasses, shrubs and trees) in contrasting climate ranges from temperate to tropical environments (Huxley 1983; Papendick et al. 1976; Torquebiau 2000). They are subject to a wide range of analysis and assessment methods (Baldy 1963; Malézieux et al. 2009; Nair 1985). This apparent diversity and even complexity of organizational models may, from a functional point of view, be structured according to nested scales from the field to the territory, in order to deliver ecosystemic services.

Multi-species Space-Time Organization

The terms and conditions of species combinations can be described in five main types (Malézieux et al. 2009; Vandermeer 1986): row intercropping, alley crops or strip intercropping, mixed cropping, mosaic intercropping and relay/sequential crops). These types combine perennial and annual plants in various configurations and for cycles of varying duration and multiple uses in all continents (Barral and Sagnier 1889). Figure 1 shows some possible spatial arrangements of systems with the combination of two crops.

Dupraz and Liagre (2008) describes several forms of incorporation of the species diversity in cropping systems at the field scale through a spatio-temporal interaction gradient conditioning the importance of interspecies competitions. This typology is illustrated in Fig. 2, which distinguishes five main types.

Perennial and annual grass, shrub and tree crops can indeed be combined at various degrees of mixing, according to various spatial and temporal terms and in similar or lower densities than those found in each monoculture.

Different agroforestry models, incorporating trees and shrubs, have been developed in all continents like European and Sudan-Sahelian wooded parks, Indonesian, Indian and Creole forest gardens, oases, mixed cropping in Cameroon,

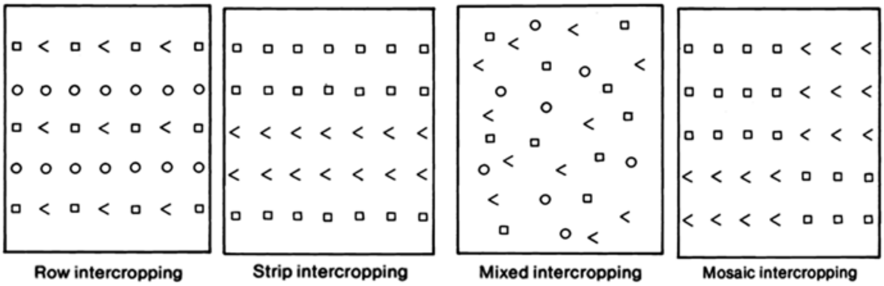


Fig. 1 Some examples of spatial arrangement of mixed cropping

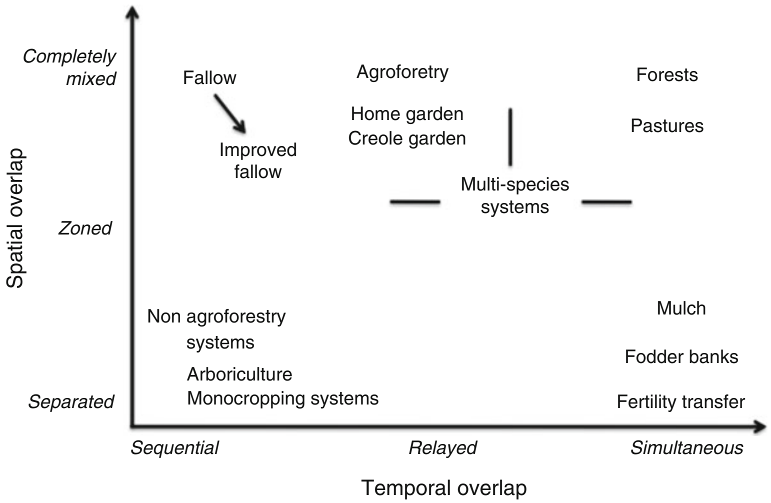


Fig. 2 Classification of multi-species systems according to the degree of spatial and temporal covering of trees and crops (Adapted from Van Noordwijk et al. 1996)

Oceania India, and Asia (Eden 1980; Fortmann and Rocheleau 1985; Klee 1980; Michon 1985; Palapiapan 1988; Nair 1979; Rabot 1982; Steiner 1985; Torquebiau and Penot 2006; Valet 1972). These mixed systems have a high graining rate with a Land Equivalent Ratio (LER), or Equivalent Density Ratio (DER) > 1, in temperate and Sudan-Sahelian areas, and a 1.1–9 arid to in tropical areas (Plate 1a–c). In the garden-forests of Java, 200 plants can be grown, more than 300 in Vera Cruz, and more than 50 trees in Bangladesh (Torquebiau 1992). These results, obtained in the same conditions, comparing mono and mixed crops, were explained by the ability of the mixed systems to provide EcoSystems Services.

According to the oasis model, beneath the canopy of various palm cultivars come the fruit trees level (up to 18 species), then the grasses and vegetable (28) food (3) and forage crops (3) (Battesti 1997). This species abundance can be explained by the fact that the farmer must take a position on different options and strategies of space, regarding the occupation of an irrigated and cultivated area which is not extensive at all, and time.

Since the 1980s, in Mali, Burkina Faso and Niger, in the dune systems of the region of Zinder and Maradi, farmers have used Assisted Natural Regeneration (ANR) on millions of hectares (USAID et al. 2002) (Plate 2a–f). Six main tree species (Gao, palmyra, baobab, néré, zizphus, parkinsonia, Lannea, hibiscus, etc.) are used (20–120 trees per hectare) to ensure the fertility of the soil (Plate 2a), food supplement to be better prepared for famines, various combinations of medicinal species and two growing seasons (Plate 2b–d), firewood and timber, and a feed supplement (Plate 2e) (Larwanou et al. 2006). Traditional irrigation (feeder-screw, watering can, chadouf), greatly improved by the foot pumps, enables to intensify the crop mix and increase its surface, as well as the duration of the growing period (Plate 2f).

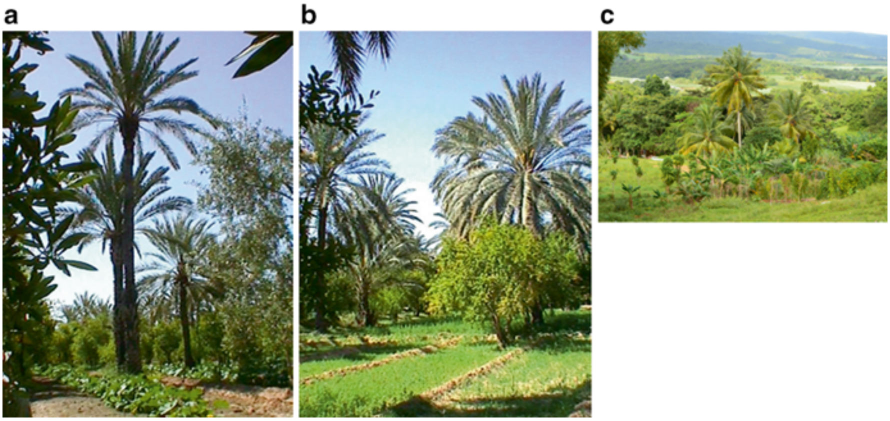


Plate 1 (**a**) Mixed crops three-stratified with palm trees. (**b**) Intercropped horticulture crops with grenadiers (Moussa 2004). (**c**) Creole garden in Guadeloupe (H. Ozier-Lafontaine 2012)

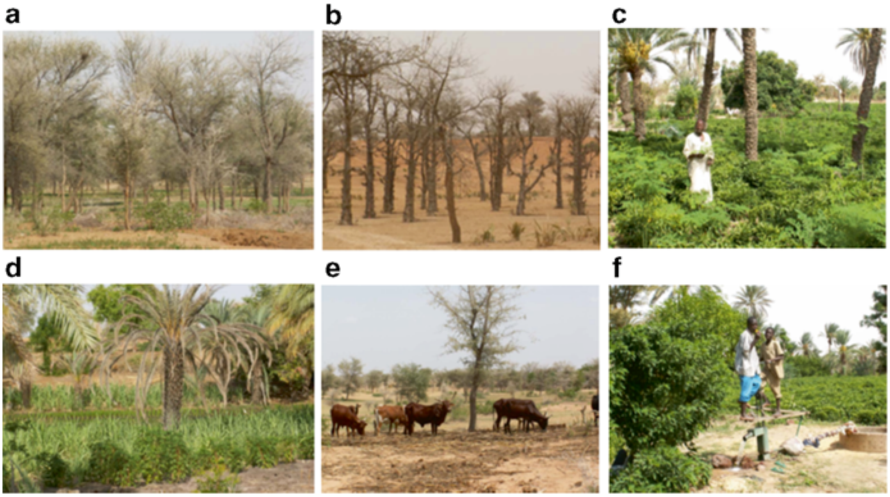


Plate 2 (**a**) Young gao (Faidherbia albida) park presenting a very high density. (**b**) A baobab (*Adansonia digitata*) park. (**c**) A basin planted with date palms, mango trees, cassava, sugar cane and rice, (**d**) palm trees with four crops a year in the fadama, Tassaou, (**e**) crops mixed with livestock and (**f**) the use of a foot pump facilitates irrigation (Chris Reij 2006)

Agroforestry practices, once common in Europe, were gradually abandoned during the twentieth century (Dupraz and Liagre 2008), mainly for reasons related to the intensification and mechanization of agriculture. A form of agroforestry combining rows of trees for timber production with intercropping (silvo-arable agroforestry) is now experiencing renewed interest since it is compatible with crops mechanization (Plate 3a and b). Agroforestry in temperate environments allows

Plate 3 (**a**) Pollarded maples, inserted in the vineyard in the Pyrenean piedmont (S. Guillerme). (**b**) Mechanized agroforestry system combining poplars and wheat on alternate spaced lines in the south of France (LER = 1.3) (Dupraz in Malézieux et al. 2009)

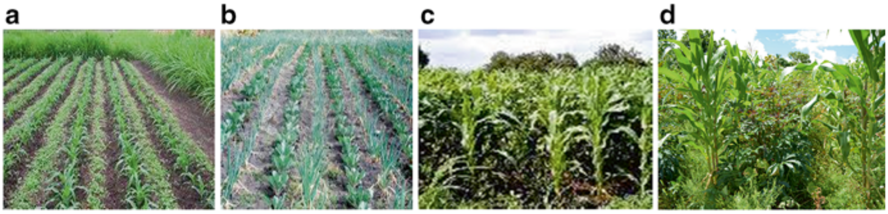


Plate 4 Different annual bispecies combinations: (**a–b–c**) grain/legumes (Séguy et al. 2008) and (**d**) annual plant based multispecies combinations (manihot/maize/cucumber) (Guadeloupe, H. Ozier-Lafontaine et al. 1998)

farm diversification, combining a steady income generated by a continuous crop production with the introduction of standing timber.

Recent studies show that some agroforestry systems could be up to 30 % more productive than crop rotations with agricultural fields on one side, and afforestation of farmland on the other, with food grain and forage production (Anil et al. 1998; Dupraz et al. 2004; Graves et al. 2007: Lithourgidis et al. 2011). Politically, agroforestry is particularly highlighted for its agri-environmental performances. It could be a particularly efficient means to fight against soil erosion, nitrate pollution of rivers and aquifers, standardizing landscapes and biodiversity loss.

From Sahelian to tropical zones, mixed cropping, not including fodder crops, shows an apparent disorder which actually falls within the scope of a sustainable spatial and temporal distribution. It takes into account the different symbiotic services as well as the antagonisms between species (Autfray 1985; Baldy and Stigter 1997; Ahmed et al. 2007; Ducret and Grangeret 1986; Kleitz 1988; Trenbath 1976; Valet 1972, 1976, 1999) as it is illustrated in Plates 4a–d and 5a b.

Thus, under these climate conditions, the constraints resulting from water and soil conditions imprint the types of annual and perennial plant combinations and

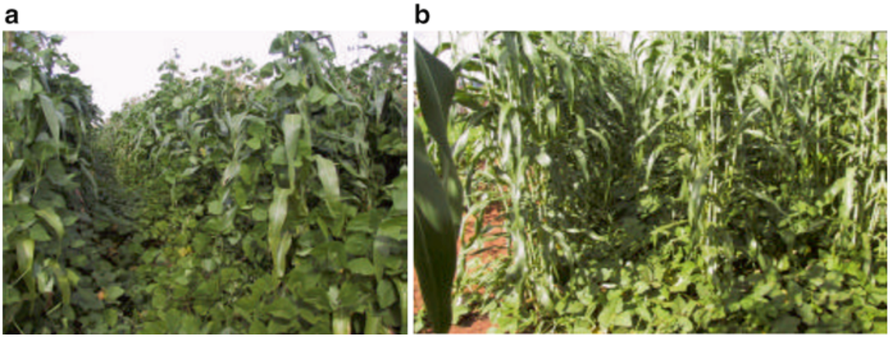


Plate 5 Combination (**a**) maize/cowpea and (**b**) sorghum/beans (vigna), in Madagascar (Photos Séguy 2003)

often provide higher yield than any monoculture even in extremely unfavourable conditions (Dancette 1984).

Criteria for Differentiating the Types at the Field Scale

When two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between them using the niche differentiation concept. To achieve this, four criteria need to be considered: (i) spatial arrangement, (ii) plant density, (iii) maturity dates of the crops being grown, and (iv) plant architecture. Even if the possible combinations are endless on a theoretical level, in reality, the degree of complexity of the systems is constrained by parameters depending on the size of the plants, the complementarity or antagonism between species, the microclimate and its variations, the sunlight, the various stress factors, the technical mastery and, to some extents, of the current prices (Ducret and Granget 1986; Dupriez 1980a; Valet 2004).

In the Sudano-Sahelian zone, even in a drought, the land use indices of a bispecies combination millet/cowpea ranged from 0.85 to 1.73 depending on the variety (Dancette 1984; Diagne 1987). The yield of millet is strongly and inversely correlated with the density of *leucaena.* Improvement of indigenous systems is also likely, as there appears to be a response to tile management of the major tree species concerned that enhances their favourable qualities (Charreau 1974; Miche 1986). With the improvement of soil and climatic conditions, the number of crops, typically from bi to tri-species in the temperate and Sudano- Sahelian zones, ranges from 12 to 300 species ha^{-1} in the humid tropical zone.

When the agro-geological context vary from bad to good like in the upper tropical zone of Western Cameroon, 2–46, are specially adapted thanks to the modulation and evolution of density, distribution and species. Their density on the ridge has a

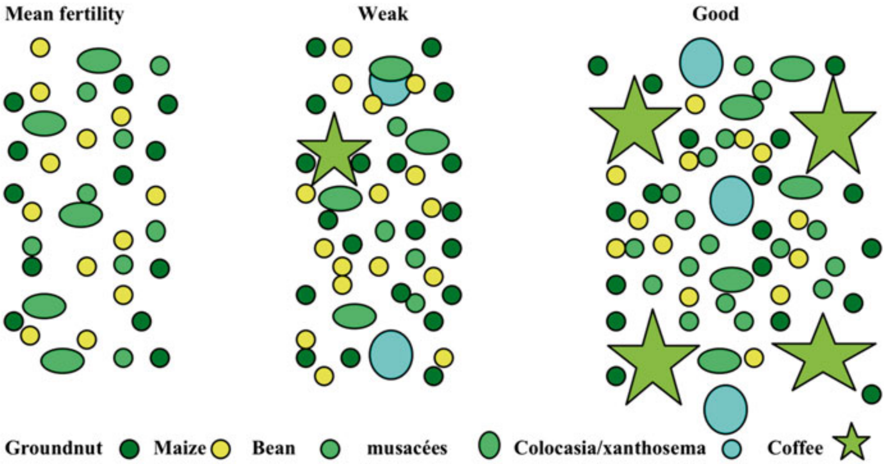


Fig. 3 Evolution of mixed cropping spatial arrangement in first season according to soil fertility (Valet 1972, 1974b)

land use Ratio from one to nine (Autfray 1985, Baldy and Stigter 1997; Kleitz 1988; Leplaideur 1978; Ravignan 1969; Valet 1976, 1999).

The plant disorder attributed to intercropping, being only an appearance, it is interesting to identify the unit cell that can be found in all environmental conditions. This 'unit cell' hinges is defined around the couple maize/groundnut with or without trees (coffee/cocoa and/or others) (Fig. 3).

The typology is very complex because all the geometric forms of combination can be found along the slopes of the different agro-geological landscapes (Kleitz 1988; Valet 1976) (Plate 6a–c). It is possible to identify the dynamics which is a driving factor of multi-cropping systems differentiation (Valet 1968, 1974b).

Fotsing (1993) notes that half a century of scientific popularization was not enough to convince all farmers to abandon traditional techniques. In 1991 only 5.5 % of farmers have adopted the contour ridges. The lush and healthy intercropping, the excellent apparent structural stability of cultivated soils, even on steep slopes, and the healthy eating of the population over centuries, contradicted the agronomists' assertion that *'the Bamileke farmers did anything, anywhere, anyhow'* (J. Praquin, an oral communication 1966) and *'Bamuns practiced a primitive agriculture'* (Tardits 1961). But the study of eight farmer's fields (five in Bamileke country and three in Bamun) under contrasting soil and climate conditions, provides information on this dynamics and the criteria used to identify the different types. Thus, in these fields, the land use Ratio varies from 1.04 to 9 in Bamileke region for identified plants, and from 1.44 to more than 2 in Bamun region for identified plants outside trees (Valet 1968). Comparable DER were measured in Menua with 3.29 (Autfray 1985) and south-central Cameroon with 1.49 (Leplaideur 1978; Ravignan 1969). And the farmers vary quantitatively (DER) and qualitatively (species and varieties) to meet various

Plate 6 (**a**) Agroforestry combination in Bafou. Dry season: trees, sweet banana and plantain, beans (vigna), tubers (dry season) (Photo S. Valet 1999). (**b**) Food crop combination in Foumbot: corn, cocoyams, groundnut, phaseolus, tubers, sweet potatoes, (1,200 m) (Photo S. Valet 1968). (**c**) Food and industrial crop combination, edge of the M'Bos plain. Oil palm, robusta coffee, corn, tubers (850 m) (Cliché S. Valet 1968)

morpho-pedo-hydro-climatic criteria and species tolerances as shown in Fig. 4a, b (Valet 1976, 1999).

But other factors such as the risks of erosion, distance from markets, monetary needs, organoleptic and food needs, changes in local, national and international prices, are taken into account by farmers. Thus the sum total of the land use Ratio

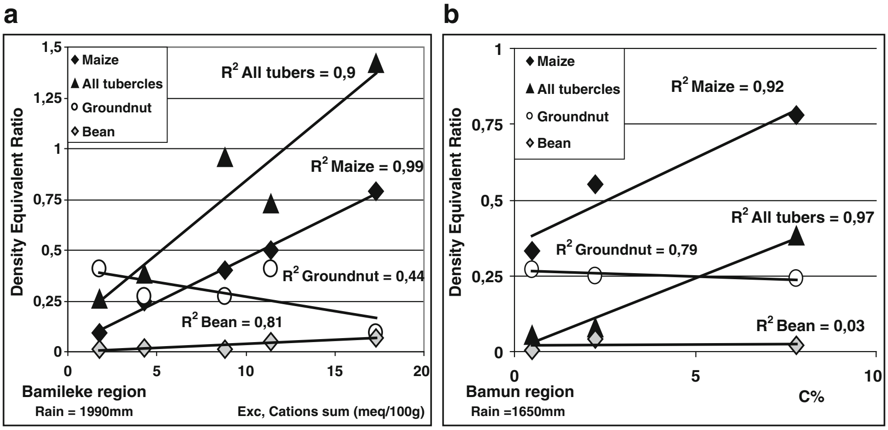


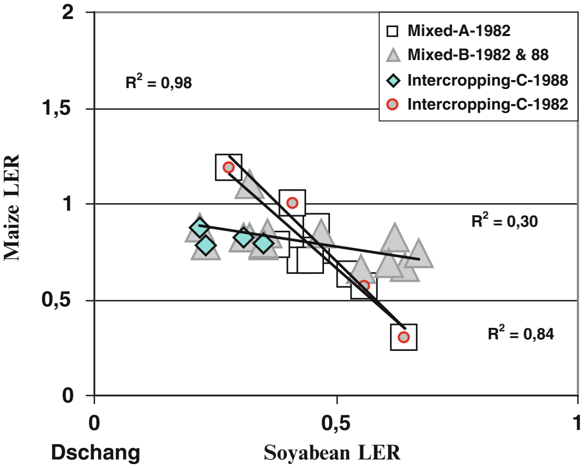
Fig. 4 (**a**) Maize, groundnut, bean, and tubercles DER vs and cations exchange sum (Bamileke region) and (**b**) C% (Bamun region) according to climatic drought risk (Valet 1976, 1999)

gradually moves from the poorest to excessively rich soils, from 1 to 2.9 in Bamileke region and 1.4–2 in Bamun region. In line with the increase in corn density, farmers have reduced that of groundnut and beans (cowpea). But there is an antagonism between bean/maize and groundnut/cowpea. The land use Ratio of the other species does not seem to be dependent on fertility. The corn/bean affinity was confirmed by Autfray (1985) and Kleitz (1988). Both authors identify a corn/bean affinity. Moreover, these authors report a conflict of peanuts with trees, Musaceae, coffee, taro and cocoyam. This incompatibility is also observed between corn/soybean intercropping (Valet 1999). From the first 4 years over 10 years of experimentation, Salez (1990), showed a strong antagonism between the LER for this combination, but with a total LER superior to that of the monocrops (1988) (Fig. 5).

This antagonism, which limits the overall production of the combination, can be explained by the competition for light and its effects on photosynthesis (Clark and Francis 1985). This is one of the reasons why this combination has not been adopted by farmers. A similar repulsion was observed between millet and cowpea in Mali by Hulet (1986) and Klaij et al. (1994), except with a supplement of P, and 21 kg of P ha^{-1}.

Farmers adjust the land use indices to less than 2 and less than 1.5 respectively for the climate and soil drought. After harvesting corn and legumes, farmers sow cabbage, potatoes, eggplant, peppers and beans and leave fields in fallow. Only taro, yam, macabo, sweet potato, banana, pepper, eggplant, sugarcane, remain for several consecutive years. Combinations are not only excessively more complex, but also, regarding the cultivated plants (species and varieties) they evolve very rapidly as a result of the very strong dynamism of the farmers which adds to the existing diversity (Kleitz 1988).

Fig. 5 Alley (C) and mixed (A, B) cropping of maize vs. soyabean LER (1982–1988)



It would be simplistic to limit these combinations to only three types as proposed by Autfray (1985) and Kleitz (1988). Farmers also use all forms of combinations described in Fig. 1, intercropping and relay, similarly taking into account the current soil fertility variation. In the first year, the taros/cocoyams (macabos), which clean the ground, prevail on clearing. In the second year, maize is favoured on rich soil, and groundnut and vouandzu (*voandzeia subterranea*) on poor soil. Both of them are top of the two types of rotations.

Tests conducted in Cameroon on a trispecies combination showed that the best yields were to be observed only in mixed cropping arrangement for maize and cocoyam for high yields, and for taro intercropping in low as in high yield (Fig. 6a–c). In Foumbot, on rich soil, Samson and Autfray (1985) found that the traditional mixed arrangement for a combination maize/soyabean is far preferable to intercropping arrangement. The influence of the spatial arrangement for three plants is obvious but less decisive than for the much more numerous and heterogeneous combinations as demonstrated by Lamanda in Vanuatu (2005). It was also showed that intercropping or mixed arrangement could in turn provide a better yield in grain or straw according to the values of the legume DER under satisfactory rainfall conditions. The small number of sites offset by their choice still allows proposing reliable rational conclusions.

In Brazil and in Madagascar, in small family farms as in field crops, the technique of Permanent Soil Cover Technology (PSCT), based on SeBoTas rice, favours multi-species and varied row and relay combination as recently been practiced: Soya + (Corn or Sorghum, + *Cajanus cajan* or *Crotalaria spectabilis*), Soya + (Corn or Sorghum + *Stylosanthes guianensis*), Soya + (Corn or Sorghum + *Eleusine coracana* + *Cajanus cajan* or *Crotalaria spectabilis*), Soya + (Sunflower + *Crotalaria spectabilis ou Stylosanthes guianensis*) (Séguy 2003; Séguy et al. 2008; Husson et al. 2010).

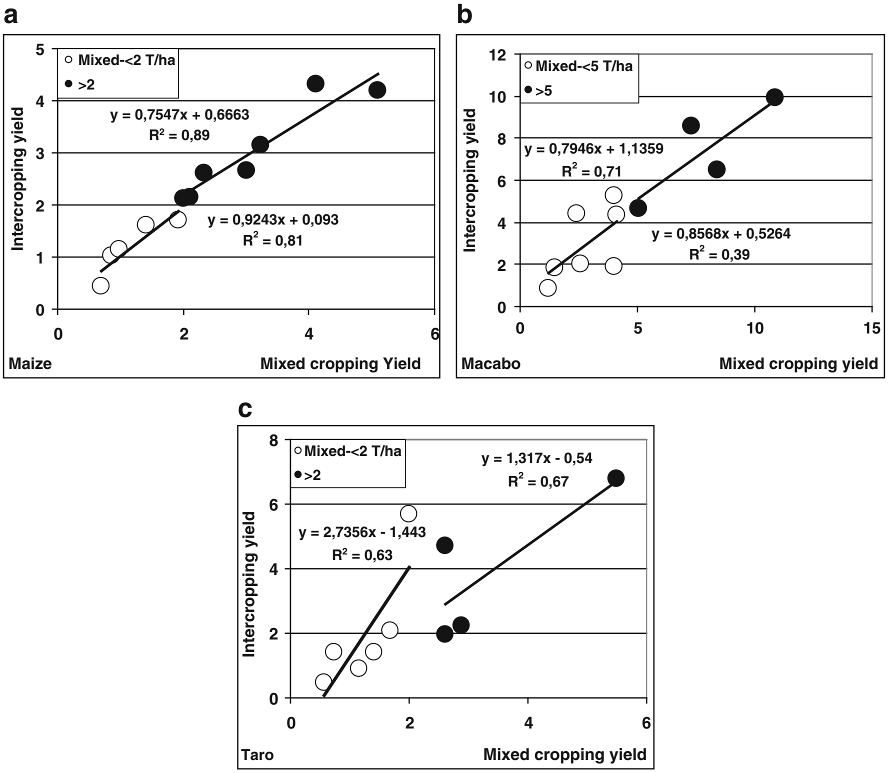


Fig. 6 Mixed cropping vs intercropping yields (T ha^{-1}) for two yield levels of (**a**) maize; (**b**) Xanthosoma and (**c**) Colocasia (West Cameroon 1968–1971)

Criteria for Differentiating the Farming Systems at the Watershade Scale

The permanence of a species or group of species or a particular system depending on the position on the slope in the watershade shall be adopted.

In the most rainy and hot tropical zones, a system as crops with or without coffee, cocoa, palm tree, grassland, forest, agro-forest, cultivated park has been made possible (Lamanda 2005). In the forest-savannah transition zone, cocoa-palm tree and fruit trees are commonly combined in center Cameroon and coffee – cocoa in Guinea with varying densities (Jagoret et al. 2012).

In the Sudanian zone, still complex combinations (two to about six species), either mixed or in row or in relay can be found on the slope (Valet 1984; Reij 2006) (Plate 7a and b). This variability is conditioned by the variability of the water supply. Indeed, along the slope, a water runon can be seen (Valet 1995). It plays the role

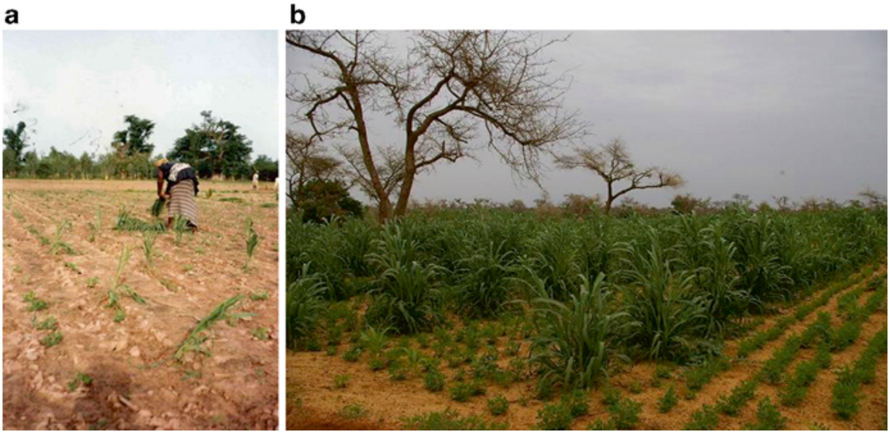


Plate 7 (**a**) Pricked out millet in groundnut field on footslope (Senegal). (Cliché S. Valet 1984); (**b**) groundnut and millet in 'park with Fhaiderbia' (Niger) (Cliché Chris Reij 2006)

of an additional irrigation to the rain which generated it depending on the surface and slope condition. Bouzinac et al. (2009), in the context of the doubly green revolution, have tested upland rain-fed sebotas rice combined and in rotation with other crops which not only help expand their geographical area to very irregular rainfall regions (Far N-Cameroon), but also conquer huge soil units considered infertile (*'Hardé'* soil of N-Cameroon) or underused [*Vertisolic 'Karal' soils of North Cameroon; iron baring, very acid, substantially desaturated high-altitude soils (1.000 m) of the Plain of Jars in the region of Xieng Khounag in Laos*].

Different cropping subsystems have been defined and arranged in terraces on the slope depending on soil fertility. Atop the hill, come first the meadow and the fallow, then the mixed food crops, then the mixed food crops and coffee, around the huts comes the garden with banana trees, then in the thalweg comes the raphiaie receding in front of the dry season gardening especially near markets (Fig. 7). Each side is remodeled physically and micro-climatically, specially by the type of crops imposed by climatic and soil characteristics. The small fields and quickhedges structure practiced by farmers with a rational distribution on the slope of living and dead quickhedges reflects bio-technical, agricultural, social and economic concerns. These systems ensure a saving of land, due to a maximum use of the land surface, and of time (Hecq 1958). It contributes to a significant overall increase in biomass production per unit of area.

Criteria for Differentiating the Farming Systems at the Territory Scale

These species distributions on the slope are also developed on the granitic hills of Central Africa especially among the Bashis in the DRC (Democratic Republic of Congo) where the banana plantation forms the ecological and economic backbone

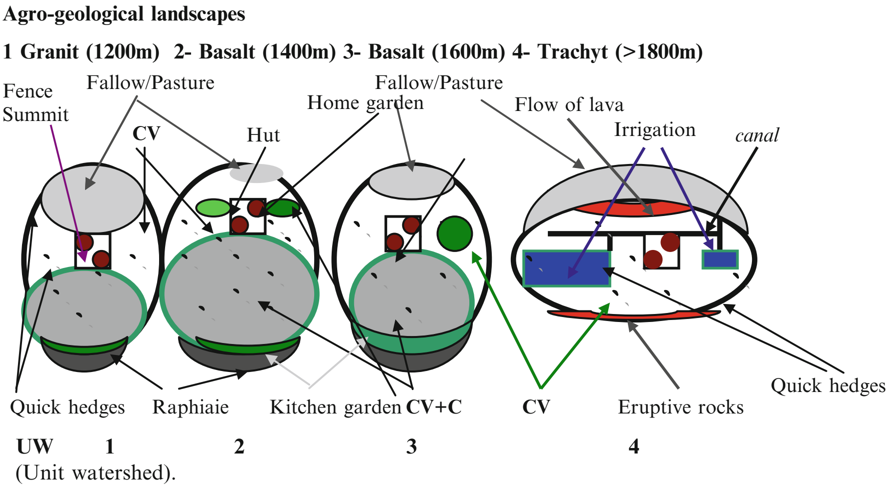
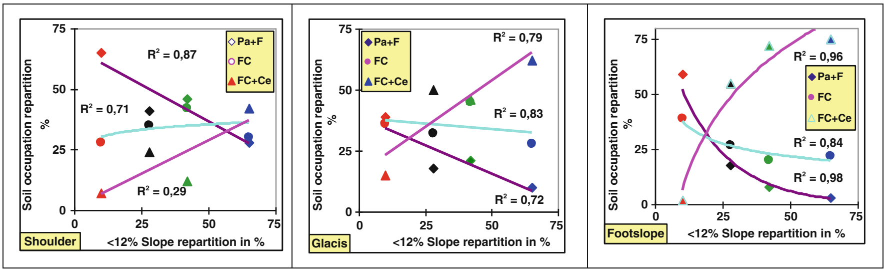


Fig. 7 Scheme of type distribution of innovative traditional and agricultural subsystems on the slope according to agro-geological landscapes and microclimates (West Cameroon) (Valet 1980, 2007)

of agro-systems (Dupriez 1980a, b; Hecq 1958; Ravignan 1969). The combination of coconut alone with food crops and other perennial crops is practiced in many countries and has led to the rise of agroforestry systems of varied nature in Asia (Das 1999) and the Pacific (Manu and Halavatau 1995). In Vanuatu, agro-forestry is based on coconut alone or with cocoa combined in different farming systems with fruit trees dominating food gardens (Lamanda 2005). In Burundi, farmers have, for 50 years, greatly complicated their systems implanted in rings on the hillsides around the *"rugo"* (enclosure) by the introduction of cash crops with a touch of finely reasoned intensification (Cochet 2001).

For the Bafu chiefdom, near Dschang, West Cameroon, the physiographic analysis of the unit watersheds explains the spatial distribution of cultivation sub-systems described in the previous paragraph for each agrogeological landscape. On the slopes, the hillsides of the agro-geological landscapes can be divided into three series (Slope ≤12 %, 12–25 % and ≥25 %). Indeed, Valet (1999) showed that soil fertility, characterized by the land gradient at different levels of the slope (top, mid-slope, down slope) for each unit watershed of different agrogeological nature, explains the extreme variability of mixed cropping systems observed on 486 fields but not explained by Autfray (1985).

The variability of the three major mixed cropping systems [mixed food crops without coffee (FC), with coffee (FC + Ce) and Pasture and fallow (Pa + F)] is due to the geomorphology and distribution of fertility on the slopes and between geo-facies and climate (Valet 1974b, 1999). There is an excellent correlation between the percentage of these systems and the percentage of the lowest slope (≤12 %) on the three positions of the slope depending on altitude (Fig. 8a–c shoulder to foot-slope). At the top of the slope, the Pasture-Fallow system decreases whereas the mixed Food Crops and Coffee system increases, the mixed Food Crops system



Red : >2000m: trachyt and acid rocks; **Black**: 1600-2000m: Basalt; **Green**: 1200-14000m: Granit; **Blue**: 1400-1600m, Basalt.

Fig. 8 Percentage of ≤12 % slope vs percentage of agrarian systems occupation according to the agrogeologic landscapes fertility and the altitude for three hill slope positions (a-Shoulder; b-Glacis; c-Footslope) at the region scale. Pa + F = Pasture + Fallow; FC = mixed food crops; FC + Ce = mixed food crops + coffee

remains almost constant (Fig. 8a shoulder); in the middle of the slope, both mixed Food Crops and mixed Food Crops and Coffee systems increase whereas the Pasture-Fallow decreases proportionally (Fig. 8b glacis); and down the slope, only the mixed Food Crops and Coffee system increases sharply although not proportionally whereas the other two systems decrease (Fig. 8c footslope). The part occupied by Pasture, compared to Fallow, decreases from 38 % to 10 % down to 0 % at the top and from 40 % to 0 % down the slope, as the mixed Food Crops and Coffee systems increase. The presence of coffee is generally an indicator of the good fertility of the down slope geo-facies, and more specifically on basalt than on granite at 1,400 m.

The spatial distribution of agricultural systems is an empirical knowledge of the quality of agricultural land spread over agro-geological landscapes and covering a very broad spectrum of fertility, but also of the effects of climate.

In Chinese agriculture, intercropping has a 1000-year old history (Dong Zhou and Qin dynasties -770–206 BC) and is still widespread in modern Chinese agriculture (Knörzer et al. 2008; Li 2001). The monocropping systems have to be revised and may not be the best performing systems any more, considering sustainability, income security and nutritional diversity in rural areas. Therefore, intercropping systems about 28 million ha (Li et al. 2007) offer alternatives for a more sustainable agriculture with reduced input and stabilized yield. Intercropping (strip and relay intercropping) may be a suitable strategy to do so as multiple crops can be grown simultaneously over space and time offering the chance for a better use of solar radiation, nutrients and water over the growing period. Intercropping bears more advantages and is more than maximized field exploitation (Vandermeer 1989). Intercropping a cereal–cereal association such as wheat and maize become increasingly popular in irrigated areas and in the North China

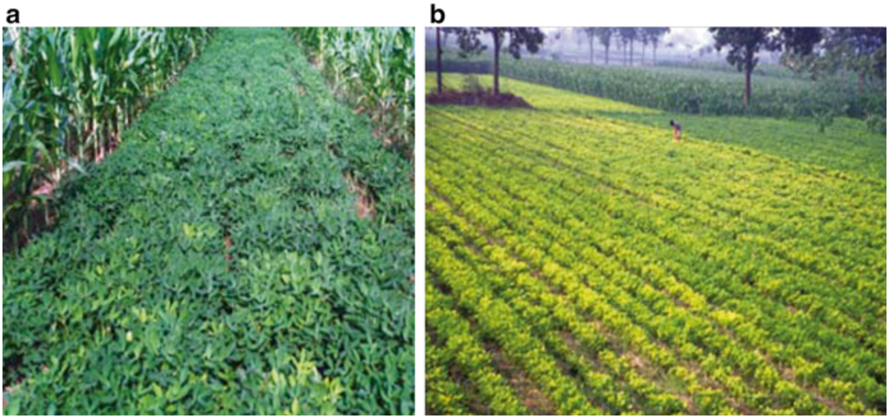


Plate 8 Intercropping of maize and peanut reduces iron chlorosis in peanuts on calcareous soils (**a**, **b**): differences between (strip) intercropped (l.) and monocropped (r.) peanut in the field (Pictures: Zhang, F. in Knörzer et al. 2008)

Plain. Both species grow together for about 70–80 days and yield more than 12,000 kg ha^{-1} (Zhang and Li 2003). Hence, a traditional cropping system could turn out to be a modern one (Lu et al. 2003; Zhen et al. 2005; Knörzer et al. 2008) (Plate 8a, b).

The knowledge of the heterogeneity and the spatial and temporal structure of the "*unit cell*" or micro-landscape at the field scale (Burel and Baudry 1999), of the agro eco-geological landscapes at the slope scale, and of the mix of these landscapes at the territory scale, is a prerequisite for predicting the ecological dynamics of a region. The levels of a natural organization, or resulting from agricultural practices, are stable only if the geo-morphological and climatic context of the place is respected (Burel and Baudry 1999). In these systems multi-terraced intercropping systems, each field is governed by a particular agricultural, economic, soil, social, use, transmission, gender (male-female), collective/individual status. At the field scale, the tree or several trees of variable density according to the soil and climatic conditions, is a typological feature (Valet 2011a). This feature has been noted by other researchers (Autfray 1985; Kelty 2006; Kleitz 1988; Torquebiau et al. 2002). For an efficient simulation, it would be interesting to check whether agroforestry, as practiced in tropical forest areas, retains the trees distribution of the primary forest corresponding to the distribution of the branches of a single tree per area of a given size, that is to say a fractal structure described by Enquist and Niklas (2001).

As described above, the temporal and spatial diversity of multispecies systems is broad, because of its adaptation to the environmental constraints, economic pressures and the strategy of farms. These systems are often more productive while ensuring the sustainability of ecosystems. This is due to multiple free EcoSystemic Services (ESS), shared by the plants themselves and with the biotic microorganisms components that grow there.

Multi-species Systems and Ecosystemic Services

General Context for the Analysis of the Ecosystemic Services Provided by Multi-species Cropping Systems

An increase in cultivated biodiversity (whether species or allelic) created through multi-species cropping systems (MCS) is generally associated with increased biological efficiency (Reddy and Willey 1981) while the provision of a variety of services – water, changes to the microclimate, protection against water and wind erosion, protection against disease and predators – also contributes to increased yields (Jolliffe 1997). Furthermore, multispecies cropping systems can contribute to a reduction in agricultural and economic risk and improve working conditions (Dupriez 1980a, b; Dupriez and de Leener 2003; Gomez Delgado et al. 2009; Malézieux et al. 2009).

The concept of ecosystemic services – a process whereby agricultural ecosystems produce benefits for society – introduced by the Millennium Ecosystems Assessment (MEA 2005), offers a more comprehensive analytic framework for classifying services, as well as disservices, liable to result from multispecies cropping systems. The services provided by ecosystems and the stock of natural capital that produces them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet (Costanza et al. 1997). These **EcoSystemic Services** can be divided into four major categories:

- Provisioning services include production of food, water, fiber, fuel, and genetic resources.
- Supporting services include primary biomass production, nutrient cycling, nitrogen fixation, and soil formation.
- Regulating services include regulation of climate, water quality, disease and arthropod pests, natural hazards, and pollination.
- Cultural services include inspiration for art and spirituality, as well as opportunities for recreation, ecotourism, and education.

Malézieux et al. (2009) propose an initial redistribution of processes and properties induced by multi-species systems, without however arranging them on the basis of Millennium Ecosystems Assessment's proposal.

Table 1 is a proposal for an organization grid of the **ecosystemic services** produced by the multispecies cropping systems. On this basis, it should be possible to provide a more complete illustration, with a bibliography, of the experiences and results obtained from the ecosystemic services provided by the multispecies cropping systems while stipulating that a service can be provided by means of a combination of several processes.

Table 1 Generic conceptual framework for the classification of ecosystemic services provided by multi-species cropping systems

Major types of SES	Agricultural and no-agricultural services	Resource or process	Scale P: Parcel C: Catchment
Provisioning	Productivity	Differentiation between niches (space, time, functionality): use of the existing resources in the environment (light, water, minerals)	P
	Food, wood, fiber, and energy	Organoleptic improvement	
Supporting	Sequestration of C	Soil covering	P and C
		Leguminous species	
		Organic matter accumulation	
	Nutrient cycle	Addition of nutrients	P
	Soil formation	N fixation	
		Recycling nutrients	
		Trapping nutrients	
		Stopping leaching of nutrients	
		Conservation/transfer of fertility	
Regulating	Protection/conservation of water and soil	Protection against water and wind erosion: soil covering/limiting runoff, improving the catchment area, modeling, planting in contours	P and C
		Inhibition of the formation of crusts and reducing soil	
		Evaporation by covering the ground and using wind-breaker hedges	
		Biological plowing (sol engineering: earthworms, roots, termites, etc.)	
	Regulation of plant pests and diseases	Dilution effect	P and C
		Repulsion effect	
		Physical barrier	
		Habitat effect (niche for harmful predatory insects)	
		Pest control effect	
		Orientation of trophic networks (macro and micro biodiversity)	
		Allelopathy	
		Coil covering vs. weeds	
		Predators on pests	
	Climate regulation	Sequestration of C and GES limitation	P and C
Socio-economic and cultural	Economic function	Risk-spreading	P and C
		Production for sale/own consumption	
		Weighting of variations in local, national and international prices	
		Social peace	
		Financial and food self-sufficiency	
	Social and cultural function	Ritual/cultural customs	P and C
		Curbing the exodus from the country	
		Ecotourism – wellbeing – education	

Provisioning Services

Effect on Plant Productivity

Productivity per area unit can increase when crops are associated, if compared with single crops (Willey 1979), or not if conducted in wrong conditions. Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops, which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore 1993; Morris and Garrity 1993; Tsubo et al. 2001). We must also report that biotic factors as supported by mycorrhizae, bacteria, fungi, termites, collembles, insects etc., play an equally important role (Derelle 2012).

In normal rainfall conditions as well as in low rainfall, at the same input level, numerous researchers have demonstrated the supremacy of combined crops under all types of geo-morpho-pedological conditions.

Bispecies Associations

The main associations between cereals and legumes provide variable LERs dependent on the distribution of populations of:

- 0.97–2.6 for maize and legumes (French beans, soyabeans, pigeon peas, coriander, cowbeans or cowpeas) in India, Cameroon, Senegal and Nigeria (Ahmed and Rao 1982; Dancette 1984; Djangar et al. 2004; Hugar and Palled 2008; Marer et al. 2007; N'tare et al. 1987; Odhiambo and Ariga 2001; Salez 1990; Shetty 1987; Ullah et al. 2007).
- 1.04–1.24 for Barley intercrops with Austrian winter pea (*Pisum sativum* sp. *arvense* (Chen et al. 2004).
- LERs of 2.12 (1998) and 2.01 (1999) of Sorghum-Peanut intercropping (Langat et al. 2006).

For the Association of Tubercles with Legumes/Maize

- LERs of the sweet potato + bean variant of 1.69–1.79 depending on density of beans.
- LER varies from 0.98 to 1.6 for the yam with maize or peanut, mixed cropping favours yield per unit of area and, in intercropping, the size of the tubercles (Cornet 2005; Lyonga 1980; Odurukwe 1986).
- tomato-cowpea produces LERs of 1.08–1.31 depending on their respective densities (Obedoni et al. 2005).

Table 2 Ratio of equivalence of N and P_2O_5 efficacy in maize – bean/soybean intercropped

	Doses	EER	EER
Mineral fertilization	Kg/ha	Maize/soybeans	Maize/beans
N	40	3.53[a] (6)	2.36 (5)
P_2O_5	50	1.45 (2)	1.93 (1)

FEER = [kgU-1 of intercrop 1/kgU-1 of monocrop 1] + [kg/U-1 of intercrop 2 kg/U-1 of monocrop 2 + [kgU-1 of intercrop 3/kgU1 of monocrop 3]

[a](6) Number of trials

Trispecies Associations

The maize-taro-Xanthosoma association produces LERs of 1–2 (Valet 1968, 1972, 2007) and maize-soybean-bean and maize-xanthosoma-bean in Cameroon (Salez 1990).

This LER variability can be explained by the density and even the geometry of the seedling plantings and how much mineral or organic fertilizer they are given.

Multispecies Associations

In West Cameroon, food plots have an LER of 2.35 with coffee and 1.44 without coffee, the latter plantings being on low-fertility soil (Ducret and Grangeret 1986).

Effect of Mineral Fertilization Approvisionning

Impact of Practices

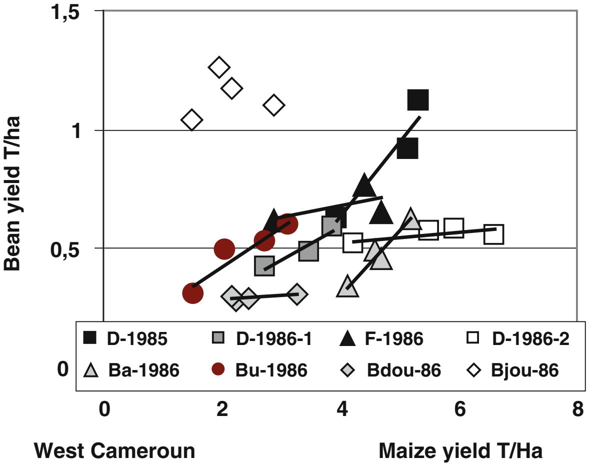
Bispecies Associations

In Cameroon, the Fertility Efficiency Equivalent Ratio (FEER) of bispecies (Maize-Bean/Soybean) association in tests using increasing doses of N and P_2O_5 shows that low doses of fertilizer have an efficacy of between 2.3 and 3.5 greater when in association than in monoculture in the case of N and 1.5–1.9 in the case of P_2O_5 (Table 2).

In Senegal, the yield from a millet-cowpea intercropping produced a LER of 1.44 with fertilizer (100 NPK) and 1.73 without fertilizer and 1.48 and 1.70 respectively for the grain and straw. Bispecies (Maize-Bean) association in Cameroon maximized maize as well as bean yields under any pedoclimatic conditions (Fig. 9) (Salez 1990).

Ofori and Stern (1987) obtained LERs of 0.96 through 1.82 with the application of fertilization consisting of more than 100 units per ha of N. But for lower doses of up to 100 units, the LER decreases. Yet Hugar and Palled (2008), using intercropping with doses of only 75 N, 75 P_2O_5 and 37 K_2O on maize and 25 N, P_2O_5 and 60 K_2O on cowpea, obtained LERs of 1.18 through 1.35. This could result, however, from the respecting density of plantings and roots that play an effective role in

Fig. 9 Positive correlation of maize yields and bean yields grown in association. (Sites = *D* Dschang, *Ba* Bansoa, *Bu* Bamendjou, *Bdou* Bamendou, *Bjou* Bandjou)



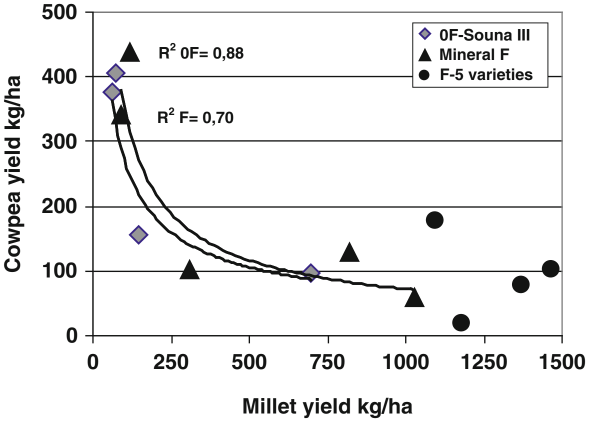
photosynthesis and Biological Nitrogen Fixation (Hardy and Havelka 1976; Peoples and Craswell 1992; Ofori and Stern 1987).

The direct and indirect transfer of atmospheric N from legumes to non-legumes, in this case cereals, may also be affected by physical, pedological, and climatic factors (Hulet 1986) proved in Mali that a delay in the planting of cowpeas for 1 week in relation to millet increased the effect of the contribution of 15 units of N by 75 % on the millet grain yield (Control planting 734 and 1,000 kg ha^{-1}). As a consequency, a 50 % dose of the recommended level of fertilizer for monocultures was the optimum dose for intercrops (Ahmed and Rao 1982; Dupriez 2006), sometimes less with leguminouses (Huley 1986; Natarajan and Willey 1986; N'tare et al. 1987; Shetty 1987; Zougmoré et al. 1998).

Optimal doses of P varied from 30 through 50 U ha^{-1}, as against 100 U ha^{-1} in monoculture, as confirmed by Harmsen et al. (2001) who found 40 Units per ha^{-1} in a wheat-lentil association in Syria, with rainfall of 250–650 mm. In Mali, the millet-vigna association increased the millet yield by 15–103 % (Hulet and Gosseye 1986). In normal years, the average LER (16 fields) was 2 (Millet = 1537 kg ha^{-1} and cowpea = 1112) (IAEA 2002). In average and good years, the LER for millet and cowpea varied from 0.96 through 1.96 with optimum doses of P of about 50 – a more efficacious environment than for millet.

During absence of nitrogen fertilizer, intercropped legumes will fix nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi et al. 2007). This 50 % saving in additives (fertilizer and pesticides) was noted by Séguy et al. (2008) in a permanent '*Direct Seeding Mulch-based cropping system*' and multifunctional association in Brazil. With respect to the maize-bean association, a parallel increase of the two crops can be observed. The reduction in the effectiveness of nitrogenous fertilizers is due to the fact that in these associations, the legumes increase the number and weight of their nodules ensuring the transfer of nitrogen to non-leguminous plants (Thompson 1970).

Fig. 10 Cowpea yield vs. millet yield with (F) or without (0 F) urea with increased water satisfaction in the Sudan – Sahel region



In a bispecies association (Maize-Soyabean), both mixed and in intercropping, a strong antagonism was observed, comparable to that observed with the peanut due to the shade produced by the maize (Valet 2004). This antagonism increases with density, one crop suffering as the other thrives (Soybean density of 243,000–303,000 ft ha^{-1} and maize density of 36,000–41,000 ft ha^{-1}). Yet this antagonism does not seem to have an adverse effect on overall yield. The LERs are fairly constant regardless of how the DERs are distributed between the two plants (LER = 1.39 on average).

Furthermore, high levels of soil nitrate can be a potent inhibitor of N_2 fixation because then the legumes thrive without fixing atmospheric N. Competition for N in a cereal/legume mixture acts as a stimulator for N_2 fixation. Intercropping reduces nitrate accumulation and the risk of loss through soil leaching, pollution, and water in comparison with monocropping.

In Senegal, the millet-cowpea association, in conditions of high water stress, with or without urea, showed a negative correlation of yields (Valet and Ozier-Lafontaine 2013). Most of the cowpea yield in comparison with that of millet reduces with the increase in water satisfaction (Fig. 10).

This shows that when water satisfaction is low, the cowpea is more resistant than millet whereas, when satisfaction is better, because the crop is sown later, it needs less feeding. The same asymmetric competition, where one species dominates another, e.g. wheat intercropped with maize, results from the greater root proliferation of high-yielding species underneath each other Li et al. (2007) showed that intercropped wheat had a greater root length density compared to sole-cropped wheat, occupied a larger soil volume and extended under maize roots. Roots of intercropped maize were limited laterally to about 20 cm, whereas roots of sole-cropped maize spread laterally about 40 cm. The failure of maize to extend into the soil immediately under wheat may help to explain why maize does not respond positively to intercropping until after the wheat harvest (Li et al. 2007).

Table 3 Efficacy Equivalence Ratio (EER) of N and P_2O_5 in tri species crop associations

	Doses	EER	Doses	EER	EER
Mineral fertilization	Kg/ha	Maize-colocasia-xanthosoma	Kg/ha	Maize-soybean-bean	Maize- xanthosoma -bean
N	75–90	3.06 (9)[a]	80	1.73 (1)	1.43 (2)
P_2O_5	75–100	1.42 (3)	–	–	–

[a](9) Number of trials

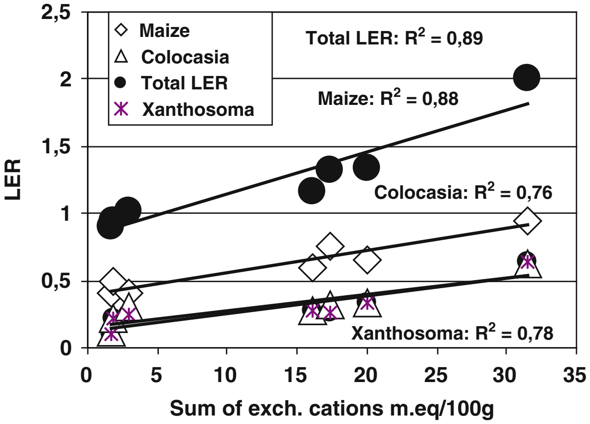


Fig. 11 Relationship between total LER, the LER of maize, Colocasia and Xanthomona and current soil fertility (sum of the exchangeable cations in m. eq./100 g) in West Cameroon (1968–1972) (Valet 1999)

Valet (1968) obtained a positive response between maize-colocasia-xanthosoma. LER, from 1 to 2, and soil fertility on Bamiléké and Bamoon regions (Fig. 11).

Association of Tree Plants

For increasing doses of N and P2O5, the N*P Efficacy Equivalence Ratio (EER) of three types of trispecies association, show that low doses of fertilizer have an efficacy 1.4–3 times greater in association for N and 1.4 times for P_2O_5 than in monocultures (Table 3).

These results were confirmed for two and tree plants by Ahmed and Rao (1982); Hulet and Gosseye (1986); Mhandawire (1989); Traoré et al. (2004); Valet and Motelica-Heino (2010); Valet (1968) (Fig. 11).

Association of Five Plants

On the pioneering fronts of central-north Mato Grosso, upland rice which until 1985, was merely a crop used to break in new land and was quickly replaced either by extensive grazing land or by soybeans, has now become the main association crop (Table 4) (Séguy and Bouzinac 1994).

With only four plants out of five the LERs in reasoned associations vary from 3.3 to 9 in comparison with traditional associations.

In the Republic of Congo, the LER is 1.52 with a 50 % saving in inputs. The 50 % of inputs (fertilizers and pesticides) were noted by Séguy et al. (2008) in a

Table 4 Average agronomic performance of cropping systems based on upland rice, in two village communities in the Cocais and Maranhão regions, 1981 (Séguy et al. 1982)

Systems	Area	Fertilizer	Herbicide	Rice	Maize	Cowpea	Manihot	Partial LER
0.5- CAT-Va	2 ha	Yes	Yes	3,940	512	143	11,270	4.9
0.5- CAS-Va		No	No	(1.70)[a]	(1.40)	(1.83)		
1- (R-Ma-R)-Vt		No	Yes					
1- (R-Ma-R)-Vt	1.5 ha	–	Yes	3,157	249	91	10,304	3.3
0.25-CAS-Va		Yes	Yes	(1.37)	(0.68)	(1.17)		
0.25-CAS-Va cm		Yes	Yes					
0.5 CAT – V	1.5 ha	Yes	No	5,535	450	173	2,321	5.8
0.5 (R-R-R) V		Yes	Yes	(2.40)	(1.22)	(2.22)		
0.25 CAS – V		Yes	Yes					
0.25 CAS –V cm, cc		Yes	Yes					
0.75 CAT – F	1.75 ha	Yes	Yes	6,194	881	305	3,309	9
0.50 CAS – F		Yes	Yes	(2.70)	(2.39)	(3.91)		
0.50 CAS – V cm, cc		Yes	Yes					
CAT itinerant control – T	1.5 ha	–	–	2,310	368	78	–	–

Note: CAT: traditionally associated crops; CAS: associated systematized crops; R: rice; Ma: manihot; V: improved varieties; T: traditional varieties; cm: average cycle; cc: short cycle

[a] (1.70) LER

technique using multispecies and multifunctional permanent '*Direct Seeding Mulch-based cropping system*' in Brazil.

Organic Matter Sequestration

The soil organic matter content can be increased by conventional inputs as manure, compost, green manure, straw, etc., but also preserved by cultural techniques, such as fallow lands, rameal chipped wood, quickhedgerows, wooded parklands.

Fallow land: The mixture of cereals and forage and food legumes nourishes the soil, thanks to its high biomass content, with a high sequestration of organic C in Brazil even in very depleted soil (Séguy et al. 2008). This was verified by Salako and Tian (2001) in Nigeria and Autfray (2005) in Ivory Coast using a single cover plant that was rich in organic matter.

Wooded parkland: In Senegal, the presence of *Faidherbia albida* in the fields, an '*ancestral tradition*', makes it possible to establish production differences of around 150 % between plants in the immediate vicinity of the trees, in comparison with those that are further away (Charreau and Vidal 1965). The production due to the presence of this species has been estimated at 25 % (Depommier 1996).

Quickhedgerows: The quickhedges allow and increase in fertility and yield, especially by the uptake of nutrients and the biomass produced, 102–124 kg ha^{-1} year^{-1} of N, 6–9 kg ha year^{-1} of P_2O_5 and 18 kg ha^{-1} year^{-1} of K_2O (Köning 1992). In Burundi,

Plate 9 (**a**) Quickset hedge at Bafu in field and (**b**) bamboo traditional fence around case at Dschang with very dense mixed cropping during drought season (West-Cameroon) (Pictures Valet 1999)

on the other hand, they eliminate runoff and prevent water retention (Duchaufour et al. 1996). as well as through trapping CO_2 (Roose 1994). It improves the structure of the andosoils that are sensitive to erosion (Casenave and Valentin 1989) and it ensures land reclamation (Barral and Sagnier 1889). On Reunion Isle, on steep slopes and in a tropical climate, a quickhedge of *Calliandra calothyrsus* improves the structure of erosion-sensitive andosols (Casenave and Valentin 1989).

Wooden fences are also effective in stopping sediments and trapping nutrients while protecting poultry, pigs, sheep and goats (Plate 9).

Rameal Chipped Wood (RCW): it is based on the use of twigs (with a diameter of less than 7 cm) that are fragmented and would normally be considered as waste products of no use (Barral and Sagnier 1889). Rameal Chipped Wood can be provided by pruning/trimming quickhedges and trees in the associations (Dodelin and Valet 2007). They represent a source of energy through the slow breakdown of the lignin which produces stable carbon (Lemieux et al. 1999). The effect of boxwood wood chip is six times greater than that of manure and three times greater than that of compost (Barral and Sagnier 1889; Djediou 2006, oral communication; Noël 2005). They play a specific role in:

- reducing runoff and erosion (Wakindiki and Ben-Hur (2001);
- the soil's microclimate;
- improvement of depleted soils through contributing nutrients;
- protection against attack and disease (Chervonyl 1999);
- stifling weeds;
- increase in production (Ayuk-Takem and Cheda 1985; Kalemba and Ndoki 1995; Furlan and Lemieux 1996; Lemieux 1994; Mungaï 1995; Thé et al. 2001).

Table 5 Comparison in yields (T ha^{-1} and LER) of several maize varieties and a local yam variety in monoculture and intercropping (Ayuk-Takem and Cheda 1985)

	Pure cultures (T ha^{-1})		Intercrops (T ha^{-1})		
Varieties	Maize	Yam	Maize	Yam	LER
COCOA maize	6.5	–	4.7	17.8	1.60
SAW maize	5.7	–	5.7	12.5	1.33
COCOA control maize	6.6	–	5.6	11.6	1.21
Local yam	–	21.7	–	–	1

Table 6 Comparative effects of Maala burn-beating, slash and burn and pure cultures of slash and burn, burning and mineral fertilization on intercropping associations, in relays, and in monocultures

Cultural systems	Traditional mixed cropping		Pure cultures	Plant LER	
Practices	Maala burn-beating	Slash and Burn	Mechanized tillage	Burn-beating	Slash – burn
Maize	2,880[a]	720[b]	3,300	0.87	0.22
Groundnuts	1,700[b]	1,200[b]	2,010	0.85	0.60
Pigeon peas	800[a]				
Yams	5,600[a]				
Cassava	22,000[b]	11,100[b]	19,000	0.58	
Partial LER				2.30	0.82

[a] 1 year mixed cropping
[b] Relay cropping during 2 years

Kalemba and Ndoki (1998) showed that the application of prunings from *Cassia stipulata, siamea and spectabilis* provided cowpea yields of the same value as 50 units ha^{-1} of NPK (Table 5).

The development of mycorrhizas that decompose lignin could favour the colonization of several grassland species (Derelle et al. 2010). Traditional practices such as burn-beating Maala or Slash and burn, comparated to mechanized tillage practices applied to a five crops, provide LERs of 2.3 and 0.82, respectively (Table 6).

Innovation Through the Introduction of Commercial Plants with DER Modification

An analysis of the development of cultivation systems in the cotton-growing region of Northern Cameroon over the past 10 years, illustrates the local farmers' ability to innovate. The innovation processes described concern techniques for introducing crops and controlling the weeds (Muskuwaari sorghum, rainfed sorghum, peanut) and the introduction of new crops into crop rotations (Onions, cotton-soybean, local forage crops), and the use of pest controls (Dugué 2006). The production of mulch using cover crops (*Brachiaria ruziziensis, Crotalaria retusa, Dolichos lablab, Mucuna pruriens, Vigna unguiculata*) intercropped within the cereal (maize-sorghum in rotation with cotton) ensures a 50 % increase for cereals and 12–24 %

for cotton (Naudin et al. 2009). In Vanuatu, the sudden fall in the price of copra and heavy demographic pressure on the land has forced a rethink in improving traditional system based on the coconut palm and replacing the coconut monoculture with the introduction of fruit trees (Labouisse 2004; Lamanda 2005). In south-western Cote d'Ivoire, the comparison of the standard rubber tree monocrop with rubber intercropped with coffee, cacao, lemon or cola (planted in a double quickhedge with wide inter-rows of 16 m) in a field trial showed that the yield of individual rubber trees was not affected by the intercropped trees until the twelfth year, after which the difference was no longer significant (Snoeck et al. 2013).

In the forest-savannah interface area in Cameroon, on soils unsuitable for cocoa cultivation, plantations established in gallery forests with fruit tree species and oil palm provide a Shannon Weaver Ratio of from 1.97 through 2.26 in comparison with plantation in grassland (*Imperata cylindrica*) (Jagoret et al. 2012).

Improving Organoleptic Qualities

A better protein yield has been recorded (Caballero et al. 1995; Dupriez 1980a; Salez 1990). The protein values, depending on the crops, are from 30 % (Maize) to 48 % (Sweet potato) better in association than in a monoculture (Dupriez 2006). Six néré (*Parkia biglobosa*) trees in a field of millet contributes 1.4 cal, 1.1 carbohydrates, 4.3 fats and 2 proteins and with 60 *Acacia albida* the protein quantity multiplies by 3.4 (Dupriez 2006). Dupriez and de Leener (2003) calculated that a néré produces annually in grains the same nutritional value of breeding 50 chickens. In Europe in the 2002/03, 2003/04 and 2004/05 growing seasons, intercropping wheat with fava bean (Denmark, Germany, Italy and UK) and wheat with peas (France) regularly increased the nitrogen and sulfur concentration in cereal grains, hence increasing the wheat quality for bread-making. Also, barley intercrops with the winter pea strain (*Pisum sativum* ssp. *arvense*) resulted in values from 1.05 to 1.26 on a protein basis showing the production benefit of intercropping (Chen et al. 2004). Also, intercropping common bean with maize in two-row replacements improved silage yield and the protein content of forage compared with single crops (Lithourgidis et al. 2008). Furthermore, protein and vitamin extracts from the leaves of numerous edible species and others can be used as nutritional supplements for children, the sick and pregnant women since they are almost as rich as Spirulina (blue micro-algae) (Soynica - Nicaragua– Appendix 5).

Regulating Services

Protection/Soil Conservation Services

Cropping associations and the quickhedges or trees associated with them, due to high crop density, play a significant role in reducing all soil erosion from water in the topsoil and subsoil and from wind erosion. This contributes to the conservation or resilience of soils.

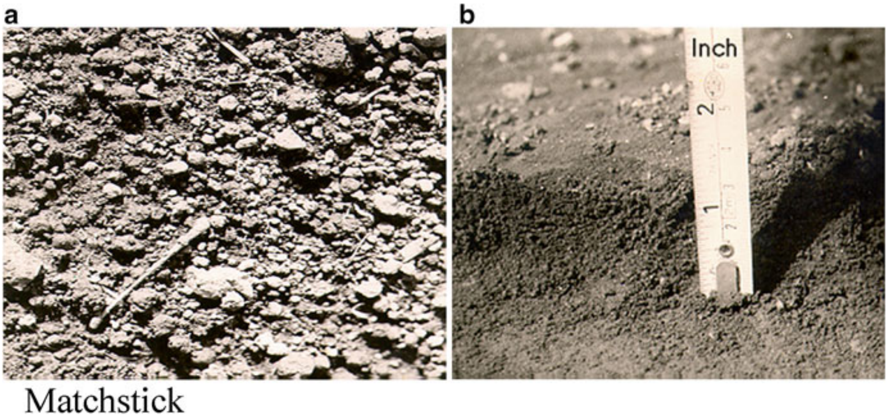


Plate 10 (**a**) Structural crust. (**b**) Stacking effect of runoff crusts shown against a stick on a vegetable plot at Dschang, gradient <1 % during 1967 (Valet 1968, 1999)

Protection Against Surface Deterioration

In West-Cameroon intensified monoculture is infinitely less protective of the soil against the ‘*splash*’ effect of raindrops that have high kinetic energy than are associated crops (Plate 10, Valet 1999). For andosol cultivated with monocrops of maize on 25 % slope, this erosion can reach 122 T $ha^{-1}an^{-1}$. This phenomenon was previously observed in the soudanian climate by Rishirumuhirwa (1996), and so in the Sudano-Sahelian by Casenave and Valentin (1989).

Erosion, however, affects the distribution of organic matter to an even greater extent with exchangeable cations and available phosphorus which are very labile and are exported to outside the plot. The pH varies depending on the types of crusts. This annual loss of nutrients through runoff soon affects soil fertility. Valentin et al. (1990), found the same tendencies in traditional peasant farming systems in northern Ivory Coast. The plant cover developed through annual and perennial multistratified associations thus dissipates the kinetic energy of rainfall and reduces its destructive effect on aggregates, preventing the formation of crusts and the removal nutrients (Aussanac and Boulangeat 1980; Tétio 1994; Valet 2004).

Protection Against Water Erosion

In Western Cameroon, at Bambui Station, at an altitude of more than 1,800 m, the monocultural intensification of maize caused serious chiselling erosion after only 2 years of cultivation in humus-rich ferralitic soil (Plate 11).

Köning (2004) showed in trials conducted over a 2-year period that associated crops reinforced by bispecies quickhedges, especially in alley-cropping, considerably reduced erosion. The efficacy of association over monoculture and even on direct plantings is significant.

Plate 11 Cutting a channel about 30 cm wide after 2 months of maize monoculture on a ridge at right angles to the slope (Bambui Station –1,800 m) (Pictures Valet 1968)

Table 7 Effect of managed water runon whether or not managed by a quickhedge on the median grain yield for millet (kg ha^{-1}) at Thyssé (Senegal)

Rainfall quantity		Excessive	Normal		Deficient	
Quick hedge					Chiselling	Plowing
Effect of chiselling	*Above site*	800	1,150	900	*Below site*	*Below site*
	Below site	1,120	850	600		
Natural	*With run-off*				300	–
Effect of run-on	*Without run-off*				750	1,150
	Test				145	155

Quickhedges reduce the water runoff coefficient in the same way that they regulate the hydraulic system (Guillerme et al. 2009; Köning 2004; Mérot 1976). The increase in pore size from 1 to 3 mm crossing the parts above, below and at 1.50 m from the quickhedge explain the increase in hydraulic conductivity to a saturation point of 46, 176 and 191 mm h^{-1} respectively at 1.5 m above and below the quickhedge. They may, however, compete for water and light (Bizimana and Duchaufour 1997; Duchaufour et al. 1996). In Sudano Sahelian zone, the quickhedge facilitates the management of the water run on (Table 7).

Protection Against Wind Erosion

By causing the topsoil to become uneven, agro-forestry systems and quickhedges that are sensibly distributed (Long 1989; Valet 1999; Zougmoré et al. 2000) reduce wind speed and wind movement (Hauggard-Nielsen et al. 2001). Rows of cereals (maize, millet) in a field with a shorter crop will reduce the wind speed above the shorter crops until 35–70 % after 35 days after sowing. and thus reduce desiccation. It mentioned taller crops acting as a wind barrier for short crops. This physical restriction on erosion translates into a sustainable productivity gain and benefits for the peasant-farmer. In Niger at Sadoré, Andropogon planted around the edge of a field of millet- reduced wind speed by 34–40 % over 40 days with an accumulation of about 225 t ha^{-1} of sand in 3 years (Renard and Vandenbeldt 1990).

Water Conservation Service

Increase in water efficiency is the result of different combinations of limitation of water losses (Grema and Hess 1994; Nouri and Reddy 1990; N'tare et al. 1987; Ozier-Lafontaine et al. 1997, 1998).

Increase in Water Efficiency and Reducing the Risk of Water Deficit

The drop in soil and air temperature reduces water demand (Gomez Delgado et al. 2009; Midmore 1993; Morris and Garrity 1993). In eggplant-groundnut intercropping, pod weight of eggplant in monocropping was low due to absence of intercrops, which leads to high water evaporation in soil area It has been shown that the millet-cowpea association in intercropping or is relay is important having been shown to be effective in the Sahel area to use the water reserves in the soil as economically as possible (Dancette 1984; Diagne 1987; Reddy and Willey 1981; Reddy and Ramanatha 1984; Van Duivenbooden et al. 2000) and in France (Guillerme et al. 2009), the intercrops have been identified to conserve water more largely because of early high leaf area Ratio and higher leaf area (Ogindo and Walker 2005). Morris and Garrity (1993) mentioned that water capture by intercrops is higher by about 7 % compared to mono crop. Willey (1979) and Tsubo et al. (2003) stated cereal-legume use water more efficiently than monocropping. Barhom (2001) reported that water use efficiency was the highest under soybean-maize intercropping compared with monocropping maize and monocropping soybean. Singh and Joshi (1994) confirmed that mixed, row, and strip cropping systems (millet-clusterbean/greengram) under severe drought conditions during reproductive phases in both seasons have a LER = 1.26. It has been shown that the water use (W_UE) in semi-arid areas is higher for mixed crops than for monocrops. Arslan and Kurdali (1996) agreed with the results of Hulugalle and Lal (1986). The two crops explore a larger volume of soil and do so more thoroughly and efficiently (Willey 1979; Thobatsi 2009). Improvement of water use efficiency (kg mm^{-1}) in intercropping

Table 8 Partial and total Water use Efficiency Equivalent Ratio (WuEER)[a] of millet-cowpea intercropping in water stress in Senegal[b]

	Pure cropping			Partial WuEER				Total WuEER	
	Yields grains (Kg ha^{-1})			Millet		Cowpea		Millet + Cowpea	
Treatment		Millet	Cowpea	Grains	Fallow	Grains	Fodder	Grain	Fallow
F0[c]	Average	359	600	1.15	1.07	0.93	1.11	2.08	2.18
F1[c]	Average	552	724	1.19	0.70	0.70	0.75	1.89	1.45

[a] WuE: varieties in kg mm^{-1}

[b] 4 trials

[c] 6. Millet F1: 150 kg ha^{-1} N10-P21-K21 + 100 kg of urea; cowpea F1: 150 kg ha^{-1} of N8-P18-K27

leads to increased use of other resources (Hook and Gascho 1988). So, two trials (millet-cowpea intercropping) demonstrated that the Water use Efficiency Equivalent Ratio (WuEER) in semi-arid areas, is higher in different mixed crops than for monocrops, for heavy water stress conditions (Valet and Ozier-Lafontaine 2013) (Table 8).

$$\text{WuEER} = \begin{bmatrix} (\text{Wu millet intercrop / Wu millet monocrop}) \\ +(\text{Wu cowpea intercrop / Wu cowpea monocrop}) \end{bmatrix}.$$

These two Senegalese trials mainly confirm the results found by different researchers (Azam-Ali et al. 1984; Hulet and Gosseye 1986), corroborated by Morris and Garrity (1993) that stated that water capture by intercropping is about 7 % greater than for monocrops.

Under normal condition cereal-legume intercropping uses water equally (Ofori and Stern 1987). Conversely, it has been shown that two or four associated species consume respectively 7–10 % (Morris and Garrity 1993; Reddy and Willey 1981) and 28 % (Sinha et al. 1985) more per unit per hectare than each monoculture.

In an area of water scarcity, intercropping is a suitable method (Lynam et al. 1986). The importance of association crops, intercropping or relay was shown in the Sahel for economising on water reserves in the soil (Diagne 1985; Van Duivenbooden et al. 2000) and in France (Guillerme et al. 2009). Furthermore, the rainfall interception by vegetation is an important factor in the water balance (de Jong and Jetten 2007). In eggplant-groundnut intercropping, pod weight of eggplant in monocropping was low due to absence of an intercrop causing high water evaporation from the soil Yet under certain combinations of conditions such as under drought and soil compaction, water competition restricts the use of water by intercropped pearl millet, forcing pearl millet to shift to the recently supplied water. In contrast, cowpea did not show any significant changes under these stressful conditions (Zegada-Lizarazu et al. 2006).

The coffee agroforestry system compared to coffee monoculture, monitored over a 3-year period in Costa Rica, showed an advantage in rainfall interception, with a water runoff of less than 56 %, and best infiltration and water content in the soil.

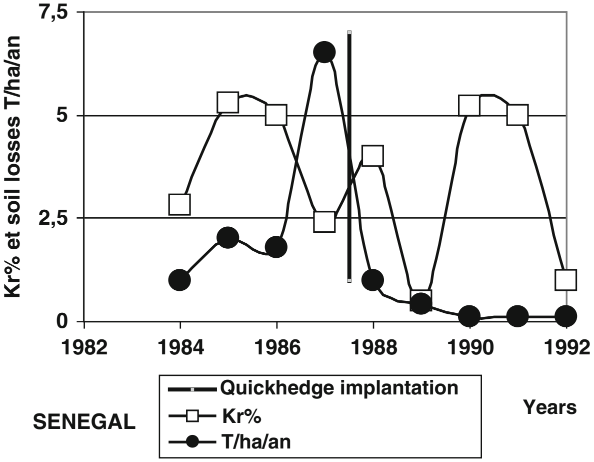


Fig. 12 Effect of quick hedges and rows of stones in reducing erosion and maintaining water runoff in a 1.5 ha watershed

This suggests complementarity for water content in the soil between coffee and the shade impact produced by *Inga densiflora* on water use and drainage (Cannavo et al. 2011).

Quickhedges in the Sudan-Sahel region (Thyssé in Central Senegal), combined with rows of stones in a watershed of 1.5 ha, reduce topsoil erosion by 90 % with a 20 % reduction in runoff from the first year (Fig. 12). Maintaining this level of runoff favours a field upstream with water runon ensuring a water surplus as well as nutrients (Ca^{++}, K^{+}, Mg^{+++}, Na^{+}, P_2O_5 and C) thus improving crop demand for water and feed (Valet 2000, 2004). Maximum millet yields increased by 250 kg ha^{-1}–1,150 kg ha^{-1} and mean yields by 145–900 (Valet 1995).

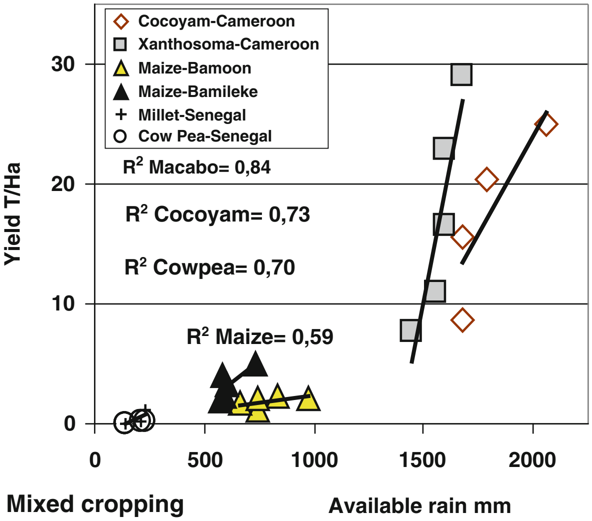
Improving Water Properties

In mixed crops especially when reinforced by quickhedges with high density during critical erosion periods:

- Favours the rate of infiltration which can reach 41 cm h^{-1} on fallow land and 81 cm h^{-1} under mulch (Rishirumuhirwa and Nyabuhwanya 1993) due to very uneven ground (Boli 1996),
- In Burkina-Faso, the Sorghum-Cowpea association reduces water runoff by 20–30 % and by 5–10 % respectively in comparison with pure sorghum and pure cowpea (Zougmoré et al. 2000).

Furthermore, a cereal-legume association acted as the best cover crop and reduced soil erosion which can attain 80–90 % (Reddy and Ramanatha 1984). In Burkina Faso, Zougmoré et al. (2000) showed an erosion rate of 80 % and 45 at 55 % respectively in comparison with pure sorghum and pure cowpea. The improvement in water quality is due to a reduction in erosion and leaching of agronomic inputs (N, C, etc.). The reduction is also the result of the interception factor of the canopy (Cannavo et al. 2011).

Fig. 13 Correlation between yield and available rain for millet grains and cowpea in monoculture and on association with tubercles (the Sahel (shown in *black*) and Sudan-Sahel to tropical zone (shown in *white*)



The reduction in water runoff also reduces the risk of pollution in lakes and rivers (Caldwell and Richards 1986; Dupraz and Liagre 2008; Innis 1997; Ofori and Stern 1987; Zhu 1991; de Willingen and Van Noordwijk 1987). Furthermore, planting seedlings in stages with their different lengths of cycle reduces nutritional and water needs since they are not the same at all times (Baldy and Stigter 1997). Competition between plants, a theory advanced by Donald (1958), is reduced accordingly.

Adapting to Climate Change by Increasing Droughtness

Contrary to certain received ideas whereby low densities reduce the risks of crop failure during drought years, an increase in the density of bispecies plantings increases yield by increasing the efficiency of transpiration over evaporation even under low fertility conditions (Hulet and Gosseye 1986; Payne 1997). In every latitude, the amount of rainfall appears to be decisive in explaining the variability of yields (Fig. 13).

Trees, with their screening and coverage effect, reduce the importance of direct evaporation on soil and wind (Gomez Delgado et al. 2009). A study of a pearl millet/groundnut intercrop (1:3 row arrangement) showed a wind speed reduction of 35 % at 35 days after planting in 1985 and 70 % in 1987. It increased the radiation use efficiency of groundnut by 21–35 % (Ong et al. 2001).

Regulating the Microclimate

Solar radiation provides energy for photosynthesis, which ultimately provides the potential for crop productivity and also determines water use by the process involved in evaporation and transpiration (Baldy and Durand 1970; Thobatsi 2009).

Intercrops have been identified to conserve water largely because of early high leaf area Ratio and higher leaf area (Ogindo and Walker 2005). There is an attenuation of solar radiation and extreme temperature variations through the reduction in albedo (Dancette and Poulain 1968; Salau et al. 1992; Valet 1974, 1976) with the maintenance of a species ambient microclimate that is more humid, having an effect on the reduction in evapo-transpiration (Othieno et al. 1985; Stigter 1984, 1994).

Ozier-Lafontaine et al. (1998) showed through a model that there was greater water efficiency in the case of bispecies associations vs. pure cultures, thanks to niche differentiations produced by colonization contrasts of the aerial and subterranean sensors, and differentials in flow resulting from the regulation of supply and demand.

"*The Iroquois also grow crops on low hills ensuring a warmer substrate for the grainlings, as well as better drainage, and preventing compaction…*" (Tremblay 2008). These methods also contribute to resistance to climate change (Valet et al. 2008). The modification of the microclimate within the canopy of the intercrop reduce moderate-to-severe disease due to a reduction in leaf wetness duration during and after flowering (Schoeny et al. 2010). Atiama-Nurbel et al. (2012) showed that the mean LER (2 years) grow up 1.31.

Root Colonization and Niche Differentiation

The root system coverage depends on the type of soil, the species, their planting density and age (Lamanda 2005). A denser root system, as well as greater complementarity resulting from better layering could be seen in mixed crops whose RER (Root Equivalent Ratio) varied from 1.2 to 1.5 (Moreau 1982), or even more (Balde 2011).

Root higher length and dry weights in a vetch/barley and barley/pea mixture were higher than those under sole cropping (Arslan and Kurdali 1996; Izaurralde et al. 1992). This ensures better soil structure, better root penetration in depth, better anchorage as well as better complementarity in the use of nutrients and water in the deeper layers in comparison with monocultures (Autfray 2005; Hulugalle and Willatt 1987; Nouri and Reddy 1990; Osseni and N'Guessam 1990; Rao et al. 1998). In a maize-peanut association the plants excrete phytosiderophores into the rhizosphere, thus becoming more efficient in Fe deficiency surroundings and benefitting from the iron nutrition of maize and of peanut (Zhang and Li 2003).

Increased root system density can facilitate the interconnection of mycorrhiza (Hauggaard and Jensen 2006). The growth of mycorrhizal fungi on and in plant roots dramatically increases the area of roots available for soil exploration of nutrients, particularly P, but also N. This complementarity of root systems via niche differentiation facilitates the use of nutrient resources and water at various depths and over time, minimizing competition, and these are high productivity factors in tree-crop associations (Caldwell and Richards 1986; Dupraz and Liagre 2008; Zhu 1991; de Willingen and Van Noordwijk 1987).

Pest and Disease Control

One of the major roles of crop associations is their ability to resist attacks by multiple pests and diseases. An analysis performed on two plots published by Risch (1983) – respectively, 150 and 209 published studies – concerning an assessment of pests and natural enemies in polyculture vs. monoculture, showed that in 53 % of cases, crop associations suffered from less serious attacks than did pure crops. on particular t the percentage of natural enemies of mixed crops is greater than in monocultures (59 % vs. 9 %), yet in only 32 % of the situations studies was it shown that there was no difference between monocultures and associations. The beneficial effect of crop associations in controlling disease and parasites was confirmed by other researchers (Rämert et al. 2002; Root 1973; Szumigalski and Rene 2005; Vandermeer 1989). But this aspect is not easy to demonstrate, since it is complex and unpredictable (Trenbath 1999). A mixture of species with very different usage/purpose is the essential condition for confusing the issue for insect pests (Lefrançois and Thorez 2012).

Six hypotheses are generally advanced to explain the ability of crop associations to regulate plant pests:

The disruption hypothesis (push): one of the associated species disrupts the ability of the pathogen to attack the host plant through confusing it: emission of volatile substances, visual effects, barrier effect, etc. (Khan et al. 1998).

- The hypothesis of the trap plant (pull): one of the associated species attracts pathogens, keeping them out of reach of the more vulnerable crop or the species attracts predators on the pests.
- The natural enemies hypothesis, based on the ability of mixed systems to favour greater diversity of predators and parasites.
- The hypothesis of micro-environment modification, involving mixed crops that can create more favourable conditions for the plant under attach or less favourable conditions for the development of the parasite, or those more favourable for the development of its natural enemies.
- Vertical and horizontal barrier effect.

The *push–pull* system (see Ratnadass and Bartzman, Chap. 3), has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans-Nzoia are reporting a 15–20 % increase in maize yield.

In Réunion Island, Deguine et al. (2012), by planting lines of maize around truck farm and horticultural plots, protected zucchini, chayotes or christophines, cucumbers, pumpkins, melons and other cucurbitaceae from predatory flies (*Bactrocera cucurbitae, Dacus ciliatus* and *D. demmerezi)* who were thus trapped.

Furthermore the association of certain species offers a protective effect (against disease) or a repellent effect (against pests) such as absinth against aphids, marigolds (*Tagetes* sp.) or rattlepods (*Crotalaria*) against nematodes (Agrisud 2010), maize and sweet potatoes (Afessa 1997) and numerous plants associated with legumes (Berry et al. 2009; Chikte et al. 2008; Epidi et al. 2008; Fernandez-Aparicio et al. 2007; Kinane and Lyngkjær 2002; Sekamatte et al. 2003).

Mixtures of winter rye with winter wheat and spring barley with oats reduced the incidence of leaf fungal diseases (Vilich-Meller 1992). This reduction of bacterial effect was about 20–80 % (Hauggaard-Nielsen et al. 2008; Sikirou and Wydra 2008).

In other cases, there is recourse to so-called ‘satellite’ plants that cover a field to serve as a trap for predators, i.e. the association of eggplants in a potato field to fight Colorado beetle (Agrisud 2010). When they meet, chayote or christophine flies are destroyed by a micro-wasp that hides in the weeds (Gamour Program: Agro-ecological management of vegetable flies at the CIRAD meeting). This technique economizes on insecticides and herbicides and improves the harvest by 60 % (page 14–15, A-F Roger). Atiama-Nurbel et al. (2012) showed that the LER in association and without spraying was 1.31 (2 years mean) in comparison with spray control.

Crop associations offer weed suppression possibilities, pest and disease control, and use of soil resources under organic farming systems (Bulson et al. 1997; Jensen et al. 2005; Theunissen 1997). Their efficiency varies with the environmental conditions. However at present, organic farmers still depend mainly on modern varieties developed from conventional breeding programs (Murphy et al. 2007; Vlachostergios and Roupakias 2008; Vlachostergios et al. 2010), but the majority of these varieties cannot face up efficiently problems as pest and fungus pathogens, weed competitiveness, or resource exploitation under organic farming systems (Wolfe et al. 2008; Lammerts van Bueren et al. 2003).

These performances can largely be explained by the barrier effect (horizontal and vertical), enabling plants to be concealed from insects, diluting the vector, modifying temperatures and the exposure that favours insects climbing up a stem (Altieri et al. 1978; Baldy 1986; Deen et al. 2003; Egunjobi 1984; Hauggaard-Nielsen et al. 2001; Kinane and Lyngkjær 2002; Rajvanshi et al. 2002; Singh et al. 1990; Steiner 1985; Tétio 1994).

Weed Control

Weed control is a major constraint in tropical wet areas. This effect produced by the action of associated crops is known (Banik et al. 2006; Bulson et al. 1997; Hauggaard-Nielsen et al. 2006; Liebman and Dick 1993; Welsh et al. 1999). It brings various actions into play that can act concurrently:

(i) increase in DER (Saucke and Ackermann 2005);
(ii) increase in leaf area index with increased light interception.

Sans and Altieri (www.ub.es/agroecologia/pdf) found that intercropping with cover crops significantly reduced the structure of the weed community but no fertilization effect was observed.

The suppression of weeds was also confirmed by Steiner (1985) when maize was intercropped with groundnuts, vigna and sweet potato leading in all cases to the reduction of weed growth, yield losses and the amount of time required for weeding. Depending on the years, the effect of weed control can be between 52 and 63 %, in pea-false flax (Saucke and Ackermann 2005) and 70–96 % in inhibiting purple nutsedge density (Iqbal et al. 2007). In the first year of cultivation the Bamilekes (West Cameroon) sow a large quantity of taro and eddoes whose large leaves smother the weeds (Valet 2011a). Intercropping leek and celery in a row-by-row replacement design considerably shortened the critical period for weed control in the intercrop compared with the leek pure stand. Furthermore, the relative soil cover of weeds that emerged at the end of the critical period in the intercrop was reduced by 41 % (Baumann et al. 2000). The high fertility levels and weed stress conditions favoured the intercropping advantage (Ayieni et al. 1984; Thobatsi 2009; Weil and McFadden 1991).

An additional benefit was the reduced Striga infestation in millet/groundnut systems (N'tare et al. 1987). There are conflicting reports on the effect of intercropping cereals (hosts) with legumes (non-hosts of cereal Striga). Three techniques were used:

(i) Similarly, a push-pull strategy for integrated Striga management has shown that fodder legumes (Khan et al. 1998).
(ii) decrease available light.
(iii) should be used for rotation instead of continuous culture

Studies in Kenya indicate that intercropping with cowpeas between the rows of maize significantly reduced Striga numbers when compared to those within the maize rows (Odhiambo and Ransom 1993). On-farm trials show that intercropping of maize and Cowpea with *Desmodium* spp. planted in the same hole in Striga-infested farmers' fields increased maize yields by 78.6 % in western Kenya (Odhiambo and Ariga 2001). Here again, *Desmodium uncinatum and D. intortum* intercropped with maize reduced Striga infestation (Khan et al. 1998). This is attributed to allelopathic mechanisms of *Desmodium* spp. that involved a germination stimulant for *S. hermonthica* as well as an inhibitor for haustorial development (Khan et al. 2002).

Thus crop associations offer effective weed suppression, pest and disease control, and better use of soil resources in organic farming systems (Bulson et al. 1997; Jensen et al. 2005; Theunissen 1997).

Supporting Services

Fertilization Transfer Services

Nitrate Fertilization

An increase in the supply of nitrogen is the result of two principal mechanisms:

- Nitrogen-fixing: the legumes associated with maize, thanks to the number and weight of their nodules, enable continuous transfer of atmospheric nitrogen into maize without reducing the efficacy of N in the soil (Dala 1974; Hiebsch and McCollum 1987; Masson et al. 1986; Mhandawire 1989; Schmidtke et al. 2004; Trenbath 1976; Haugaard et al. 2001). This additional use of the environment by most of the species has been called the "*annidation phenomenon*" (Ludwig 1950). It has been reported that the Cowpea can fix N at rates varying from 8 kg ha^{-1} year^{-1} (IRRI 1974), to 84 kg ha^{-1} year^{-1} (Johnson 1970, quoted by Skerman 1982), to as much as 240 kg ha^{-1} year^{-1} (Nutman 1971, quoted by Rachie and Roberts 1974). *Desmodium*'s N-fixing ability increases soil fertility and is an excellent forage crop.

- Reduction in leaching N and its nutrients (Njoku et al. 1984): the coffee-*Erythrina* association reduces N leaching from 14 to 2 NO_3-N (mg NL^{-1}) in relation to conventional monoculture – trees enable nutrient return, and other factors related to high productivity (Dupraz and Liagre 2008). In Quebec, Allen et al. (2004) reported an 80 % reduction in the quantity of nitrates recovered by plants thanks to the power of interception in the roots (safety net).

In France, 1 km of quickhedges can recycle 60 kg of nitrogen and reduce the nitrate content of the water by 85 % (Guillerme et al. 2009; Macary and Bordenave 2008). Harmand et al. (2007) demonstrated that the coffee-Erythrina association reduces N leaching from 14 to 2 NO_3-N (mg NL^{-1}) in comparison with conventional monoculture.

In West Cameroon, a test performed by Salez (1990) confirmed that in a maize-bean association, using the same dosage of mineral fertilizer, the maize yield increased from 1.8 to 5.2 T ha^{-1} and that of the beans increased from 0.37 to 1.1 T ha^{-1}.

This reduction in the leaching of nitrogen and nutrients (in the order of 20–30 U ha^{-1} of NPK), due to greater efficiency of use was demonstrated by Njoku et al. (1984) in a manioc and maize crop association.

However a surplus of nitrogen can cause competition between the maize and the legume. In such a case, it is preferable to cultivate them in relays to double the yield obtained in monocultures as recommended by Balde (2011) in the pedoclimatic conditions of the Brazilian Cerrados.

Phosphate Fertilization

Phosphate fertilization, after nitrate fertilization, is used much more effectively by plants grown in association than in monocultures. This is the result of several mechanisms that may act separately or simultaneously:

- A pH reduction linked to high-density root systems enables an association (a cereal –durum wheat- and two legumes – pea and fava bean – in an intercropping system) to access various forms of P, especially organic P (Betencourt et al. 2010).
- The effect can be transmitted from root to root thanks to radicular connections and more efficient use connected to the great density of the root system on the same subject of intercropping (LER = 1.5) observe that a share of a slight contribution of P is stored by bacteria which are then recovered after their predation.

Thus, in a millet-cowpea rotation, ridging and P fertilizer input increased biomass production by 10 % for millet grain, 21 % for millet straw, and 27 % for cowpea fodder, but reduced cowpea grain yields by 8 % (Klaij et al. 1994). In another experiment, tillage resulted in a 76–167 % millet yield increase (Klaij and Hoogmoed 1993).

The Organo-Mineral "*Turnover*"

The biogeochemical cycles and storage of organo-minerals have tremendous contemporary significance due to their critical roles in determining the structure and function of ecosystems, and their influence on atmospheric chemistry and the climate system. The recycling of nutrients is a critical function that is essential to life on earth. These cycles involve carbon, nitrogen, sulfur, and phosphorus but operate on different space and time scales (Ecosystem-level processes are studied in forest, grassland, and agricultural ecosystems. They are dependent on biotic and abiotic factors such as parent material (acidic and basic rocks), soils (texture and structure soil, bulk density, oxides and hydroxides, waterlogging), climate (cool, wet, desert), topography, time, micro- and macro-fauna and their activity (Bacteria, fungi, termites, earthworms, millipedes, arthropods), cultivation (forest, pasture, crops), cation bridges, fertility (total biomass above and below the soil). Heterogeneity is a prominent feature in most ecosystems. As a result of environmental heterogeneity the distribution of many soil organisms shows a temporal as well as horizontal and vertical spatial patterning Soil represents a major pool in the recycling of C from the biosphere and constitutes the habitat for terrestrial photosynthetic organisms which fix them in roots, shoots, leaves, branches and all parts of plants and animals.

Currently, human impacts on these nutrient cycles are responsible for a multitude of global changes that threaten the sustainability of ecosystems essential to mankind. In the forest-savannah interface area of Cameroon, the level of organic matter in the soil is 3.13 % in old cocoa plantations (along with oil palm, fruit trees, and coffee), as compared to 1.7 % for cocoa in grasslands (*Imperata cylindrica*) (Jagoret et al. 2012). Organic compost (Compost, loam and dung heaps varying from 1 to 5 tha^{-1}) provide the best yields in association with mineral fertilizer regardless of the level of water satisfaction (Because many of our current environmental problems are manifestations of disturbed biogeochemical cycles, the study is fundamental to an understanding of environmental issues such as global climate change, changes in atmospheric composition, land cover/land use changes, carbon sequestration, nitrogen saturation, acid precipitation, nonpoint-source pollution, and water quality. The soil biota benefits soil productivity and contributes to the sustainable function of all ecosystems. The abundance of plant waste from associations and trees/fences; trapping organo-mineral sediments using quickhedges, wooden fencing and wood chip favours the sequestration of carbon and N, effectively combats the greenhouse effect and regenerates soil (Scopel et al. 2005; Peichl et al. 2006). Peichl et al. (2006) measured the net flow of organic carbon for the agroforestry Inter Cropping Systems, in a poplar-barley combination, of 13 T ha^{-1} a against -3 T ha^{-1} for barley on its own.

Agroforestry maintains the fertility of the environment and high productivity from cocoa bushes that is greater than in conventional monoculture (Jagoret et al. 2012). In agro-forestry systems a stabilization (Sanchez et al. 1985) and even an increase in the SOM is observable (Kowal and Tinker 1959) except for cacao bushes in the sandy soils of the Ivory Coast coastline which remain deficient in organic matter.

These results confirm that the ecological techniques that increase the sequestration of ~~OC~~ with an improvement in the aggregation of soils efficiently combat erosion (Barthès and Roose 1983; Mutuo 2004). The overall result is a more effective fight than in monocultures against the greenhouse effect and soil regeneration through simple or complex stable organo-minerals (Peichl et al. 2006; Tiessen et al. 1984). In New Zealand mixed cropping short term rotations (pasture and arable) increase the aggregate stability of a group of soils mainly due to the production of binding organic carbon by virtue of the microbial biomass present in the pasture rhizosphere, and they do this more rapidly than the increase in clod porosity (Haynes et al. 1990).

Proliferation of Biodiversity and the Gene Pool

The vast range of agroforestry practices most strongly favour the potential for the conservation/rehabilitation of biodiversity (Lamanda 2005; Michon and de Foresta 1995; Schroth et al. 2004). The variety of biochemical and biophysical mechanisms variety – thanks mainly to the action of fungi – improves the formation of the soil structure (structural genesis), both directly and indirectly (Kihara et al. 2012; Ritz and Young 2004). Biological efficiency and the creation of habitats and nutritional niches promote greater stability and conservation of this biodiversity (Francis 1989). The biological efficiency of intercropping is due to exploration of a larger soil mass than in monocropping (Francis 1989). *Faidherbia* trees reinforce the microbiome (Jung 1966). Crop associations increase the quantity and number of mycorrhizal fungi and bacteria, or add them to plants that have a poor supply thereof (Derelle 2012). The increase in the microbiological mass (*bacteria and mycorrhiza*) linked to the expansion of the root system and of their exudates in associations ensure better cultivation and use of a larger volume of soil (Derelle 2012). The authors concluded that these bacteria could play a key role in N availability to plants and could be important for the interactions between plant species in intercropping. During anthesis the nitrate concentrations in the rhizosphere of wheat intercropped with fava bean were nearly twice as high as in monocropped wheat. The N released from fava bean roots was rapidly mineralized into ammonia and then converted into nitrate. This was accompanied by better stability and conservation through the contribution of organic and mineral waste from crops and trees, promoting the creation of habitats and nutritional niches (Hobbs and Morton 1999). Fungi affect the formation of soil structure (structural genesis) directly and indirectly, via a variety of biochemical and biophysical mechanisms (Ritz and Young 2004).

Economical Services

The debate about the relationship between the economy and ecology, a source of confrontation, is over (Vallée 2011). An economic assessment of the gratuitous Eco-Systemic Services is based on very different yet complementary approaches which sometimes offer each other mutual support. One can thus speak of ‘*natural capital*’ over and above which the long-term survival of the biosphere would be compromised (Vallée 2011). In view of the difficulty of assigning a price to Eco-Systemic Services provided by associated, multi-level crops – i.e. the difficulty of assessing the economic value of (micro)biodiversity (Costanza 1991). The following paragraphs will provide examples of their cost/advantage.

A provisional context for the physical accounts of ecosystemic natural capital was published in the journal Ecological Economics (Weber 2007). It can be summarized as follows (Fig. 14):

- Accounts created by type of ecosystem (stock, flows, resilience, services, pressures) on the one hand, and by industry sectors on the other (materials and energy flows, ecosystem services by origin, resources and usage, natural capital).
- Ecosystem services measured directly in cash terms (when incorporated into products) or physical units and in cash (free services for end-use).
- Costs of maintenance and restoration of ecosystems (with respect to the objectives indicated by society) in physical units and in cash.

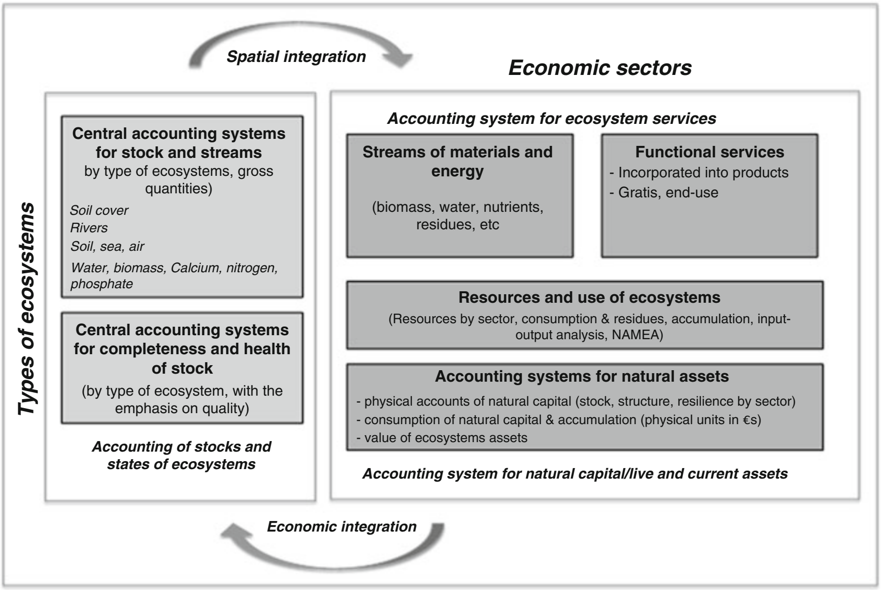


Fig. 14 Context of ecosystem accounts (Weber 2007)

- Natural ecosystemic capital in physical units only.
- Incorporation of geographical information (soil cover, rivers, topical information, zoning) and socio-economic statistics.

However, the interdependencies between the various accounts should be made explicit, especially their implications for cross-classifications and levels of details (Millennium Ecosystem Assessment 2005).

Long before there was awareness of climate change, the backlash from economic liberalism and limits of the conventional model prioritized monocrop intensification, but peasant farmers of both sexes were able to develop traditional farming systems that were nevertheless able to develop and were capable of managing the complexity of local environments while dealing with the uncertainty of local changes and national and world food prices. It is these agricultural systems that have inspired the natural ecosystems, of which farmers had sufficient empiric knowledge to convert into multi-species and multi-level associations that varied enormously in number and species on the basis of the morpho-pedoclimatic conditions and those of the societies in which they lived. They also invented new space-time arrangements in order to introduce into their traditional crops, species that were commercial and industrial, as well as truck farms and fruit trees (coffee, cacao, coca, oil-palms, cotton, bananas, coconut palms, vegetables, tomatoes, cabbages, …) on the recommendations of agronomists.

These multispecies, innovative associations produce and benefit, in the same way as traditional farming, from ecosystemic services that can contribute to sustained intensification.

Economic Services Relate to Several Main Functions

- The combination of conditions that are propitious for maintaining profitable and long-term production are based on the minimum use of synthetic inputs and fossil fuels. Production must be capable of being understood in both the short and the long term, especially with respect to reinforcing the resilience of production systems in view of the risks and uncertainties of all kinds (erosion, soil, food and water pollution, and so on).
- Risk reduction. Alongside the anti-risk logic (between zero risk and maximization of minimum income), diversification in farming can be interpreted as a response to the difficulties of accessing credit and using short cycle crops to finance crops with a longer cycle depending on climatic, topographical and pedological circumstances (Dury and Zoa 2001; Ellis 1998; Valet et al. 2008). In the case of a disease problem or one of climate impact (such as a cyclone), diversification of speculation in farming could attenuate the risk.
- The contribution of economic services to social functions. In multiple crop farming and animal husbandry, for example, the arrangement of various plant and animal training workshops, can support a more complex organization but one that is more varied and thus offers more resilience in case of the unexpected.
- Better use of time.

Beyond this, the agro-ecological advantages of these systems can contribute to restricting ultra-mechanization that leads to a reduction of the degree of use of human energy, and thus to an increase in rural unemployment (Dumont 1975). Curbing the exodus from the countryside and a reduction in the demographic pressure in cities will ensure the maintenance of social cohesion, as shown by Lamanda (2005), in the case of the peoples of Vanuatu.

Units of Analysis and Units of Synthesis, Context of the Accounts

The assessment of economic services requires a contextual analysis to be defined for the relevant indicators (Weber 2008). Alongside the classic concept of an ecosystem described as "*a dynamic complex of plants, animals, and communities of micro-organisms and the non-living environment acting in relation to each other as a functional unit*", there is a tendency to use a more comprehensive concept of socio-ecological systems that are spatial entities in which the production functions of the ecosystems satisfy social demand:

- through their conversion into saleable goods,
- or directly through the individual or collective end-use of recreational, cultural or regulatory services.

Ecosystemic accounts contribute, when incorporated into an ecosystem, a macro-ecological loop without which the assessment contributed by economic and environmental accounts is incomplete. Part of the development work in producing economic and environmental accounts has already been done, in the form of "*non-standard accounts*" for the future SEEA-2003 (Integrated Environmental and Economic Accounting System) revised and constituting an extension and update for the "*Assessment of Ecosystems for the New Millennium*" (MEA 2005). Yet the interdependency between the various accounting systems must be rendered explicit, especially their consequences in terms of cross-classification and level of detail (MEA 2005). Figure 15 shows the general articulation of the system.

Clearly, in this review, the ESSs cannot be treated fully due to lack of scientific, technical and investigative data. Only the main services have been subject to calculation or only of an estimate.

Benefits of Socio-economic Services Rendered by Multi-species Cropping Systems

Figures 14 and 15 which determine the organizational framework for national and international accounts and the main services incorporated into them, clearly show all the difficulties that need to be taken into account with respect to the effects, stocks and positive or antagonistic flows that these services may product and/or preserve. This is all the truer when reasoned on different scales of human and natural activity as well as on variable time scales. The ecological imprint of human

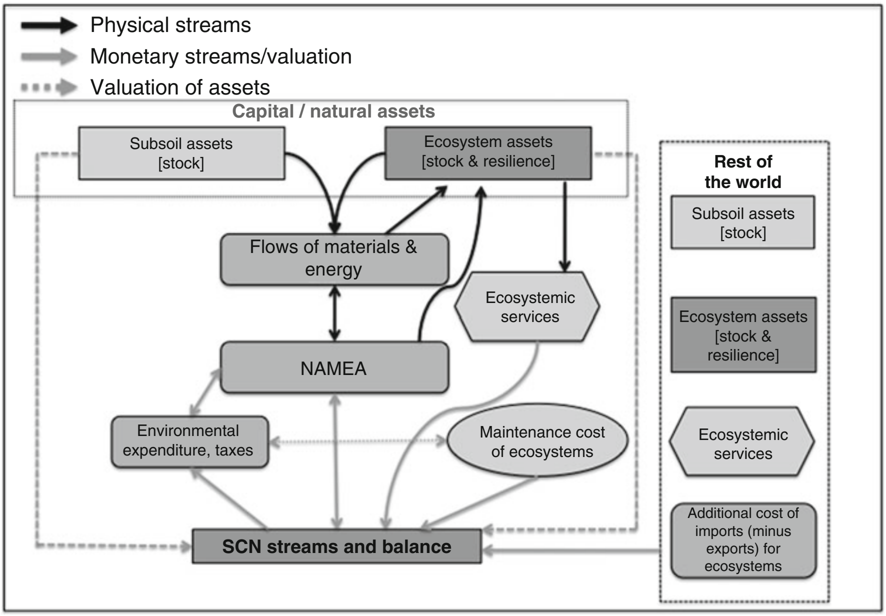


Fig. 15 SEEA incorporating ecosystems (Weber 2007) (SCN = NAS = national accounting system)

activity and inaction in relation to climate change have a cost that needs to be determined. Currently, discussions are focusing on composite or disconnected indicators and an assessment of their cost in the present and long-term future (Weber 2007). Our own assessments and those in the literature presented here are restricted to farming results and biodiversity that is restricted geographically and over time (10 years maximum). These results are thus difficult to aggregate and extrapolate beyond the regions in which they were calculated. The most frequently mentioned limitations in assessing ecosystem services are the ignorance of important benefits (regulation in particular), for the present and even more so for the future, the impossibility of adding up the values of exchanges and usage, and the impossibility of aggregating individual preferences (Weber 2007).

Regulating

They remain no less interesting since they represent a hope for other regions. An assessment of ecosystemic services will be translated into monetary terms.

Use of Biophysical Techniques Against Erosion

Biophysical control techniques against erosion provide several benefits, some of which are computable. To estimate the ecosystemic services that reduce wind and

Table 9 Assessment of wind and water erosion and climate change (flooding and drought) for different countries and by different authors (Brahic and Terreaux 2009)[a]

Country	Purpose of the study	Assessment method	Price in Euros[a]	Authors (in Brahic and Terreaux 2009)
New Mexico	Wind erosion	Replacement cost	600.98 an^{-1}	Huszar (1989)
Australia-Manilla	Rainfall	Hedonic pricing	3.07 ha^{-1}	King and Sinden (1988)
Turkey	Rainfall	Replacement cost	44.99 ha^{-1}	Bann (1998)
US- Palouse	Rainfall	As a function of production	5.82–8.73 acre^{-1}	Walker and Young (1986)
Indonesia	Drought	As a function of production	2.7–31.53/household	Pattanayac and Kramer (2001)
Cameroon	Flooding	Prevention cost	0–21.62/household	Yaron (2001)

[a] 2008 value

water erosion, and involved the adaptation to climate change has been made by area per household and per capita (Brahic and Terreaux 2009). They point some regional variability (Table 9).

Valuation of the *Push-Pull* Effect: Savings in Pesticides

In Nigeria, the *push–pull* system was tested on over 450 farms in two districts. These systems are used to deter borers and striga that attack maize crops by associating the crop with push–pull plants (*Cotesia sesamiae, Pennisetum purpureum, Desmodium and S. vulgare sudanese*). This system assures a net return of US$ 2.30 for every dollar invested (Khan et al. 1998).

The services supplied by these natural predators on aphids in ten plots in Sweden were assessed at €45.39 per ha^{-1} for the barley production function (Brahic and Terreaux 2009).

In Western Kenya, with 1,400 mm rainfall, in terms of financial returns, GS4 (two rows of groundnuts alternated with two rows of sorghum, with sorghum sown at a row spacing of 105 × 17.5 cm and groundnuts at a row spacing of 105 × 9 cm, giving a final plant population of 60 % sorghum and 40 % groundnuts) made a significant contribution. The equivalent profit ratio (IER) was 3.95 (1998) and 4.11 (1999) (Langat et al. 2006).

Provisioning

Erosion Economy

Assessment of wind and water erosion and climate change (flooding and drought) for different countries and by different authors (Brahic and Terreaux 2009).

Table 10 Assessment by different authors (Brahic and Terreaux 2009), of the costs of preservation/resilience of water quality in different countries

Country	Purpose of the study	Assessment method	Price in Euros[a]	Authors (in Brahic and Terreaux 2009)
US-Pittsburg	Diverse	Contingency/ transport cost	50.90–163.43	Smith and Desvousges (1986)
US-Millesburg	Contaminants	Cost of avoiding	14.23–36.59/ household	Laughland et al. (1996)
US-Pittsburg	Water table	Cost of avoiding	23.4 year^{-1}	Abdalla et al. (1992)
US-Ogallala	Aquifer[b]	As a function of production	16.79 acre^{-1}	Torell et al. (1990)
US-10 regions	Stopping pollutants	Cost of avoidance	5.66 billion	Ribaudo (1989)
Malaysia	Ditto	As a function of production	15.25 ha^{-1}	Kumari (1996)
US-countries	Forest and runoff	Value transfer	26.41billion year^{-1}	Dunkiel and Sugarman (1998)

[a] 2008 value

[b] Differential between the price of un-irrigated and irrigated land

Water Quality

An estimate of the preservation or resilience of water quality is very variable due to the diversity of the causes of pollution, by erosion, metals, and by the methods used, that are either technical or natural such as those that include the role of the forest (Brahic and Terreaux 2009). This variability is clearly shown in Table 10.

Spatio-temporal Valuation of Agro-forestry Production

For Multispecies Crop Associations

In West Cameroon, the calculation of the net benefits of the various associated cropping systems, both traditional and innovative, was performed through trials at agricultural stations and in the field (Valet 1968, 1976; Valet and Motelica 2008). For associations consisting of 12 food plants, the traditional manual system was worth 125,000 CFA as against 40,000–55,000 CFA in intensified monoculture of the tubercles and of – 12,000 to +12,000 CFA for maize and legumes in pure cultivation. Income from the trees, shrubs and keeping pigs and goats were not taken into account in this calculation, but they ought to be added since they occupy an important place. So the trees, if equal in age, produce three times the biomass if in an intercropping association than if grown in isolation.

The significant increase in profits is proportional to the number of plants per unit of area or DER as shown in Fig. 16.

In associated cropping, the benefits increase with the number of associated plants:

<u>In the case of intensified monoculture</u> (calculation performed solely with the cost of fertilizer thus, for these mechanized monocultures, the costs of depreciation and

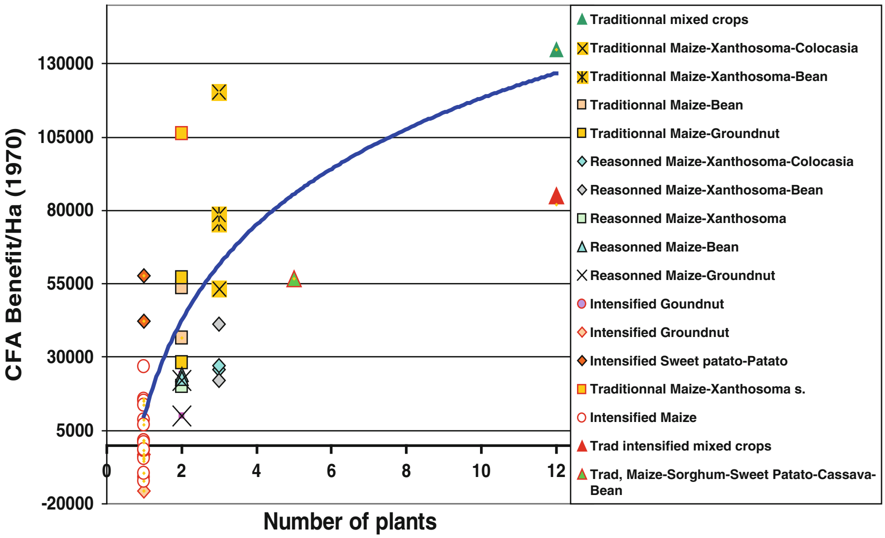


Fig. 16 Losses and benefits (CFA in 1970 value) evolution of systems vs. crop number (mono-, bi-tri-, quinqua, multi-cropping system) in West-Cameroon (Valet 2007)

machinery maintenance – grain-drill, tractor, etc. – were not taken into account, nor were fuel, the barn, grains and pest controls).

What recorded was:

- losses for soybean, peanut and maize in half the trials, and profits capped at 30,000 CFA ha^{-1} for the last two crops;
- for sweet potatoes and potatoes, there were profits of around 40,000–57,000 CFA ha^{-1}.

For Associations of Two Species

In the traditional systems, the Control planting proceeds were 55,000–105,000CFA (Maize–Xanthosoma) whereas the rational system only brought in less than 30,000 CFA.

For Associations of Three Species

There is the same cutoff point at 55,000CFA, entre le rational system and the traditional system, with maximum profits of about 12,0000CFA. Whitmore (2000) noted that in south-east Asia, the profit from associations (cassava-cover plants, rice-cassava-maize followed by legumes), was two to three times greater than from monoculture. The profits are very much greater where two tubercles are associated with maize rather than with one legume and one tubercle.

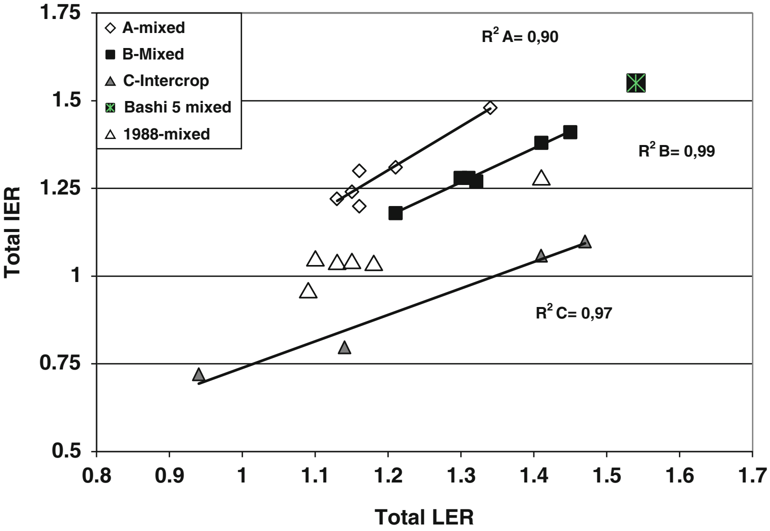


Fig. 17 Total MER vs. total LER for maize-soybean association cropping in Cameroon and the mixed maize-sorghum-manihot-potato-beans among the Bashis (Dem. Rep. of Congo)

For Associations of Five Species

With few tubercles profits do not exceed 55,000 CFA ha^{-1}.

For the bispecies maize-soybean association studied by Salez (1990) in the same regions, the profits are capped due to the antagonism of these two crops. The profits from soybean reduce with the increase of those for maize, and are greater in mixed plots than in those cultivated by intercropping, but nevertheless remain attractive (mean LER = 1.30). Shetty (1987) states that in the sorghum-groundnut association yields are inversely proportionate, in the same way as for the sorghum-millet association except at the Sikasso research station in southern Mali where the yields grew through canning.

In East Cameroon, among the Béti and Baka peoples, the seven main crops, in course of two seasonal cycles, along with gathering, fishing and hunting brought in about 100,000 CFA ha^{-1}to the peasant-farmers who relied on '*the assurance of a minimum coverage of the family's food in the worst weather year*' and income of up to more than 190,000 CFA for those who wanted to earn more by cultivating cash crops (cocoa, coffee, wood) (Webert 1977; Sieffert and Truong 1992).

Among the Bashi people, in the Republic of Congo, the LER and the IER are positively correlated (Fig. 17) (Hecq 1958).

Mixed cropping ensures IERs that are always higher than 1, while intercropping only provides 50 % of results greater than 1. For different associations, in Kenya, it was obtained higher profits in monocultures of 56–148 % (Table 11). It is interesting to note that the IER increases from 1 to 2.48 when the plants increase from 1 to 4. These results accord with for eggplant-groundnut intercropping systems those of Valet (2007) in West Cameroon.

Table 11 IER (dollar) at Zaria Upland in Kenya (Baker and Norman 1973)

	Crops		No. of hours	Income acre^{-1}		Manual labor taken into account	Total IER
No	Types	Plants	Year acre^{-1}	Brut	Net		
a	Pure	Millet, peanut, cotton	146.5	21.5	20.8	10.4	1
b	Mixed	Millet/sorghum Sorghum/peanut Cotton/cowpea	235.6	33.7	33	16.2	1.56
c		Millet/sorghum/peanut Millet/sorghum/cowpea Cotton/cowpea/sweet potato	225.3	32.2	30.8	14.7	1.41
d		Millet/sorghum/peanut/cowpea	272.1	47.7	45.2	25.8	2.48

Table 12 Comparison of the benefits of several varieties of maize and a local species of yam in percentage of the monoculture and intercropping cultivation (1970) (After Ayuk-Takem and Cheda 1985)

	Gross income in CFA		
Varieties	Pure culture	Intercrop	Profit in %
COCOA maize	249,500	403,000	62
Maize SAW	245,500	307,000	25
COCOA maize (control)	250,000	288,000	15
Price kg^{-1}	Maize =10 CFA	Yam = 20 CFA	

The peanut-cassava system of south-east Asia provides a net profit of 495 dollars (Whitmore et al. 2000). In Kenya, Wakindiki and Ben-Hur (2001) showed an increase of 60–92 % of the financial yield of wheat-vigna in comparison with the Control. In India, the net income from the bean-sesame combination was 2.57 times greater than when they were grown in monocultures (Control = 31,560). Ayuk-Takem and Cheda (1985) show that the two-species association (maize-yam) ensured a profit, depending on the variety of maize, of 15–62 % greater than in monocultures (Table 12) and Obedoni et al. (2005) for tomato-cowpea).

Other researchers, some whose work dates back 30 years, confirm an improvement in profits from intercropping in comparison with monocultures, in the USA and in India, as confirmed in 2009 (Ahmed and Rao 1982; Grimes et al. 1983; Kalra and Ganger 1980; Kurata 1986; Seran and Jeyakumaran 2009). Francis and Sanders (1978), showed with 20 trials in Colombia, the economic superiority of the improved maize-bean association with an average IER of 1.84. Furthermore, these authors showed that family manual cultivation with few inputs produced a higher IER of 1.78 as against 0.98 with mechanization and inputs and of 0.90 under heavy intensification. Family farming maximizes the area and manpower much better than under low intensification and especially with the high intensification recommended by Tourte (1971). Similar results were also reported on maize-cowpea (Pandita et al. 2000) and on maize-pigeon pea intercrops (Marer et al. 2007) (Fig. 18).

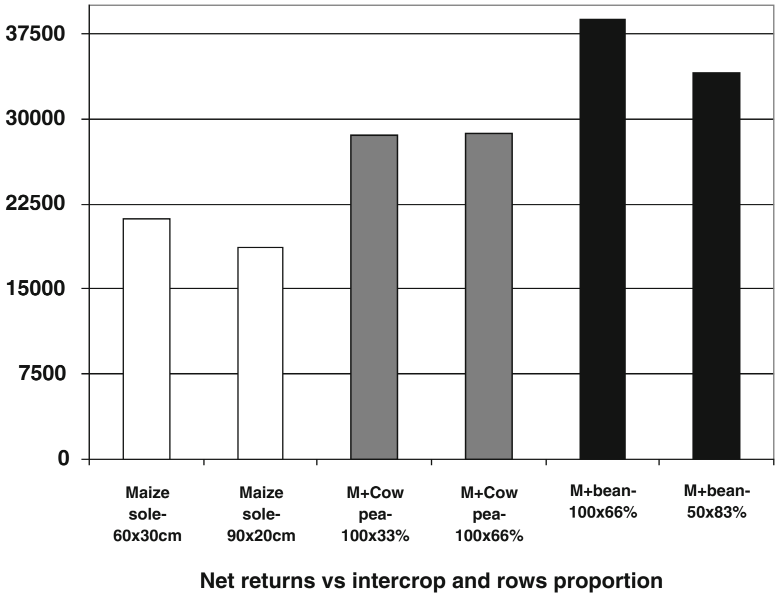


Fig. 18 Net returns vs. intercropping and row proportion for maize-cowpea-bean (Panditaet al. 2000)

The benefits are closely dependent on the proportion of respective species present. In this regard, vegetables are considered to be a profitable proposition because of additional yield and higher net returns (Prabhakar and Srinivas 1989; Pandita et al. 2000). The association with maize (DER = 1) was dominant and beans (DER = 0.6) offered the best net income.

The net margins produced by associations are significantly and very much greater than those of pure crops but with a much higher number of working days and provide high quality in all continents (Langat et al. 2006; Séguy and Bouzinac 1994; Seran and Jeyakumaran 2009; Seran and Brintha 2009).

Yet in heavily populated regions, these associated cultures would appear to represent a solution to endemic unemployment.

In Ivory Coast in the associations of rubber trees with other tree crops (fruit trees, oil palms, coffee, cocoa), rubber tree revenues accounted for 88 % of total revenues and intercrops for 4 % (cola) to 25 % (coffee). By contrast, the rubber tree-lemon tree association was not profitable due to the low price of lemons, and the rubber tree-cola association was not profitable because the cola-trees only started yielding from the seventh year (Snoeck et al. 2013).

Intercropping often provides higher cash return than growing one crop alone (Grimes et al. 1983; Kurata 1986). Intercropping occupies greater land use and thereby provides higher net returns (Seran and Brintha 2009), capsicum and cowpeas production and Langat et al. (2006), with Sorghum and peanut, radish and amaranth intercropping and capsicum and cowpeas.

Kalra and Ganger (1980) reported that intercropping helped increase farm income on sustained basis. Intercropping commonly gave greater combined yields and monetary returns than those obtained from either crop grown on its own (Ahmed and Rao 1982). Net return of radish and vegetables intercropped with amaranth intercropping correlated with amaranth (intercrop) plant density (Seran and Brintha 2009). Francis and Sanders (1978) and Brown et al. (1985) showed that illiterate peasant men and women farmers are able to manage their very complex farming systems very well financially. The 50 % devaluation of the CFA franc in 1994 increased losses of revenue in intensified monocultural systems (Valet 1999).

Examples in Europe

In Europe, intercropping agro-forestry systems compare advantageously with each other in comparison with pure crops and forestry (Graves et al. 2007). Piraux et al. (1997) confirm that revenue (excluding the cost of manpower) is only positive in extensive cultivation but are negative in intensified animal husbandry and are even more so in mechanized cultivation, corresponding to Tourte's (1971) light and heavy intensified systems.

Supporting

Add to this the various crops of wood for woodworking, forage, fruit, cosmetics, pharmacopeia, firewood and others (binding, ropes, tool handles, combs, sap, latex, rubber, leaves, wood chip, saponaceous grains, thorns, roots used as toothpicks, musical instruments,…). Quickhedges thus provide populations with the services previously offered by the forest.

Socio-environmental Services

Valuation of Work

A second method of valuing crop associations is linked to the efficiency of the work. In the case of slash-and-burn systems, the valuation of work not only involves the initial clearing work but also the quantity of work per unit of the area cultivated (Ravignan 1969). Crop systems based on upland rice, in the two rural communities in Brazil in 1981, provided a mean valuation of a day's work that was clearly of greater benefit for associated crops than for monocultures (Fig. 19). (Séguy et al. 1982). Short cycle varieties appear to make better use of manpower and significantly so with dual treatments (herbicide and fertilization). Furthermore, they

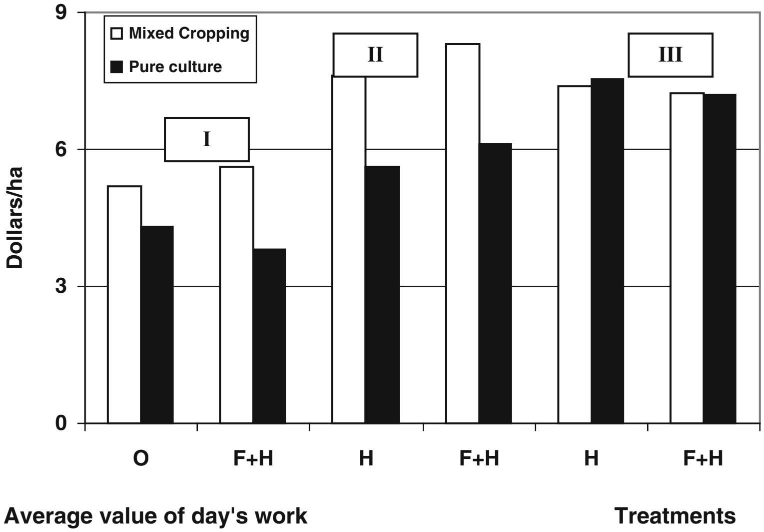


Fig. 19 Average value of a day's work in associated crop systems based on upland rice in two rural communities, Brazil, 1981 (Séguy et al. 1982)
0 = Control = without fertilizer nor herbicides
F = + Fertilization
H = + herbicides
Group I = traditional variety
Group II = IRAT 10 variety (short cycle)
Group III = IRAT100 variety (long cycle)

occupy the soil and labour for less time. This is comparable with the Melanesian or "*creole*" kitchen garden, in which there is great efficiency of labour (Baker and Norman 1975).

Upland rice, depending on the various successions and associations, presented as a marriage of convenience for setting up sustainable agriculture on pioneering fronts to replace deteriorated pasture, makes it possible to achieve significant and sustained profits (Table 13). The farming systems associated with inputs make better use of the working day than the traditional itinerant farming without inputs. Treatment A with few inputs has the same value for a working day as does C with inputs that support the effect of ecosystemic services. It would have been interesting, however, to compare these treatments with an itinerant fertilized Control and for comparable areas.

In Benin, Beauval (1991) calculated that the succession of crops associating palm trees with vineyards generated a gross profit margin of close to 120,000 F FCAha^{-1}year^{-1} (2,400 euros) taking into account the selling prices of cotton, maize, peanut and oil-palm. This proves to be regularly greater than the profit for cotton cultivated as a pure crop in the region.

Table 13 Average agronomic performances in farming systems based on upland rice in two rural communities, Cocais and Maranhão regions, 1981 (Séguy et al. 1982)

Crops	Varieties	Cycle	Treatments	Net profit in Dollars ha^{-1}	%/Control (0)	Days valuation in Dollars ha^{-1}	No. of working days (kg ha^{-1})
Mixed	Trad.	Long	Control 0	406	100	5.27	77
			F+H	399	99	5.54	72
	IRAT10	Short	H	610	150	7.53	81
			F+H	773	190	8.5	91
	IRAT101	Average	H	615	151	7.41	83
			F+H	700	172	7.14	98
Pure	Trad	Long	H	258	64	4.37	59
			F+H	232	57	3.74	62
	IRAT10	Short	H	360	89	5.62	64
			F+H	493	121	6.16	80
	IRAT101	Average	H	491	121	7.44	66
			F+H	555	137	7.02	79

Rice dominant + maize + manihot; cowpea in annual succession after rice. 2: 0 = no fertilizer or herbicide; H = herbicide only; F + H = fertilizer (60 N + 60 P_2O_5 + 30 K_2O/ha) + herbicide (Oxadiazon = 1,000 g m.a./ha). < BR > 3 Economic performance in relation to crop system + in the case of associated crops rice + maize + manihot + cowpea, not included in income from perennial crops

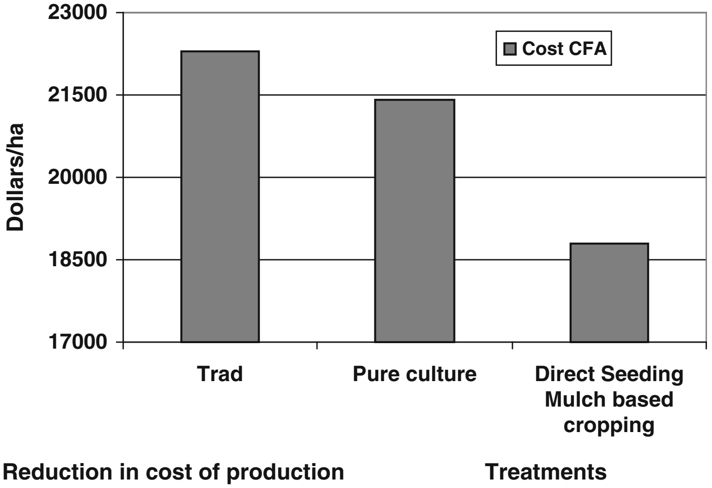


Fig. 20 Reduction in cost of production between a Direct Seeding Mulch-based cropping, associated with intensified monoculture and traditional cultivation (CIRAD et al. 2005)

In Northern Cameroon, a peasant-farmer compared the costs using different treatments. A crop planted under a vegetation cover (Direct Seeding Mulch-based cropping systems) was 16 % less costly in comparison with the traditional manual treatment in association but without fertilization and 13 % less than for an intensified monoculture (Fig. 20) (CIRAD et al. 2005).

Certainly, here again traditional manual farming is unbalanced because it does not receive the same inputs. Furthermore, in the case of Direct Seeding Mulch-based cropping systems, the depreciation of machinery and the cost of soil pollution, water and feeds and a reduction in biodiversity due to synthetic inputs have not been taken into account.

Mixed Cropping as a Strategy for Minimizing Socio-economic Risk

Taking various levels of socio-economic risk into account through a peasant strategy reduces variations in income, depending on the land and manpower involved (Dury and Zoa 2001). The choice of crops, connected with food habits, provides the answer to the difference in demographic pressure. Thus, Camara et al. (2010) showed that an association based on upland rice in the Guinean forest took up far more space (0.91 ha per inhabitant) than that observed in Cameroon (0.15 ha inhabitant^{-1}) which was based on tubercles and banana plants which have a much better yield. The choice of plants for local consumption or international export (coffee, cacao, tea, cotton, rubber, avocado, truck farms, sugar-cane, palm-oil,…) tended to increase the pressure. In addition to anti-risk logic (between seeking zero risk and the maximization of minimum revenue), diversification of farming can be interpreted as a response to the difficulties of access to credit; short cycle crops make it possible to finance longer-cycle crops depending on the climatic, topographical and pedological circumstances (Dury and Zoa 2001; Ellis 1998; Valet 1999). The logic behind the decision taken by a peasant farmer in what crops to grow involves these agricultural and agro-forestry associations combined with the imperatives to grow food (self-sufficiency, organoleptic qualities, food preservation and spreading out the harvests), as well as economic imperatives (local values, national and international prices, revenue and capitalization) and environmental constraints (rocks, soil, climate and geomorphology). This system makes it possible to keep young graduates and non-graduates in the country and to reduce demographic pressure in the cities (Lamanda 2005).

Direct and indirect economic performances which include, during bad years, minimizing losses, making savings in water, land and inputs, improving the cost of labour, and a socio-economic role explain the maintenance of associated crops on the different continents (Dupriez 1980a, b; Dupriez and de Leener 2003; Li 1990; Li et al. 2007; Malézieux et al. 2009) and this, above all, until subsidies and having, moreover, to deal with climate change (Valet et al. 2008). Socioeconomic role because of human welfare explain the maintenance of associated crops on the different continents. So in China, crop associations have drastically reduced wind erosion and pollution produced by the inputs used in intensified monocultures and have played a major economic role though one that is difficult to quantify. But Costanza et al. (1997) estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$ 16–54 trillion (1,012) year^{-1}, with an average of US$ 33 trillion per year.

The impossibility of totally or partially mechanizing associated crops either due to their large number, their different heights, the different times at which they ripen or the fact that they ripen at the same time, or due to the steep gradients of cultivated slopes has kept a large number of young people in the countryside. Continuity or introduction of these mixed crops to replace intensified, mechanized monocultures thus requires much more manpower from among family labour at a time when "*globalization*" is creating unemployment.

Contribution of Mixed Cropping to the Social Aspect: Curbing the Exodus from the Countryside

This could slow down and even stop the exodus from the countryside to the cities and to other countries in the South and North. A return to the fields from the shantytowns is to be hoped for, as long as the investments in industry capable of giving work to the unemployed have not materialized. Lamanda (2005) showed in the case of Vanuatu, that the agro-ecological advantages made it possible to curb the rural exodus and reduce demographic pressure in the cities, ensuring the maintenance of social cohesion.

Health and (Eco)Tourism

Ecosystemic services for safeguarding or reintroducing biodiversity play very varied roles. They can ensure the manufacture of new medicines, preserve hunting and develop (eco)tourism (Brahic and Terreaux 2009).

Towards an Agroecological Engineering Approach: Designing a Multispecies Framework Linking Modern and Traditional Features

Mixing Agronomical and Ecological Understanding

The link between functional ecology and agronomy was initiated 30 years ago (Hart 1986), but was not formalized until very recently (Lefroy et al. 1999). This cooperation is based upon the paradigm according to which natural ecosystems are sustainable and adapted to local constraints. Species diversity is one of the major features of natural ecosystems. Thus, contrary to conventional intensive systems which are open to strong exports, ecologically intensive agrosystems should seek to reduce the entropy bill via a networking activation of different biological functions. By incorporating some characteristics of natural ecosystems into the cultivated agrosystems, we can hopefully give them some interesting properties such as stability (Aerts 1999), resilience, in particular with regards to pests (Trenbath 1999), energy efficiency in the context of depletion of fossil fuels, productivity (Fukai and Trenbath 1993), and ultimately sustainability. The challenge is to find compromise between these different properties. In addition to the difficulty in understanding how interactions and their synergies/antagonisms are organized on the process scale, should be added the difficulty of their management, within a broader systemic framework, integrating spatial dimensions exceeding that of the plot, but also socio-economic dimensions, and this in a global changing and unpredictable environment. In keeping with this approach, agroecology and/or ecological intensification raise new questions about the concepts and tools to mobilize or create, in order to understand, act and adapt with flexibility (Jackson et al. 2010). Necessary changes should be brought both in the field of the concepts involved, and in the attitudes, for conducting research. One of the priorities to promote agroecological engineering is to intensify research on the concepts of ecology at the crossroads of other concepts provided by other disciplinary fields, to allow the analysis, the design and the assessment of agrosystems with an enhanced biodiversity.

A Prospective Study on the Concepts, Tools and Methodologies Towards an Agroecological Engineering

Engineering here refers to '*a thinking making activity that uses knowledge and technology to design and make products and systems for social benefit*'. It is one of the high stakes of ecological intensification in a broad sense, in the current trend under development around ecological engineering as an academic discipline. Mitsch and Jorgensen (2003) define ecological engineering as '*the design of sustainable systems, consistent with ecological principles, which integrate human society with its natural environment for the benefit of both*', with particular reference to the integration of natural processes contributing to self-organization and negentropy. In its attempt to redefine ecological engineering, Gosselin (2008) introduces a distinction between practical ecological engineering on the one hand, as a scope of practical application of engineering projects and scientific ecological engineering on the other hand, as a scope of application of ecological sciences, while advocating for a strengthening of the second component in terms of theories and concepts. The prospective study we are developing prioritizes the strengthening of the concepts and tools of ecology to be mobilized in order to improve our ability to analyze, model, predict and assess ecologically intensive and innovative agricultural systems.

Concepts and Tools of Ecology for Analysis and Modelling of Ecologically Intensive Cropping Systems

Specifications for ecologically intensive cropping systems and challenges for modelling

In the '*mimetic*' approach of ecologically intensive cropping systems to natural systems, notions of maximizing solar energy and microbiodiversity, structural hierarchy, structural and functional complexity and nesting, self-organization, negentropy and multifunctionality come into play. The application of these characteristics to ecologically intensive cropping systems is contingent on the strengthening of a cultivated and mixed biodiversity through the networking of bioregulations allowing to maintain the components of fertility (biological, physical and chemical) in balances that are compatible with cropping performances and the supply of ecosystem services. Reasoning these balances will require the use of concepts and methods of integration, defining a key challenge around the emergence of a new generation of models. The differentiation of ecological niches, the integration by functional traits and the thermodynamic intake can be their structuring elements. The generalization of the experimental results obtained on multispecies systems thus requires the design and use of relevant models that take into account the maximum processes and their sequential aggregation.

Niche Differentiation and Functional Traits as Structuring Concepts

Enhancing biodiversity in farming and production systems is considered as a crucial challenge for their sustainability (Jackson et al. 2010). On the scale of the cropping system, this biodiversity can be controlled in time, by crop rotations and sequences, and space, via mixed cropping, cover crops and agroforestry (Malézieux et al. 2009). Compared to pure cultures, the search for a better efficiency in the use of the environment resources by optimizing the spatial or temporal occupation of resource niches is a central issue, the purpose of which is to control the interactions allowing the selection and conduct of associations of the most complementary species according to environmental contexts.

The traditional and innovative management exercised by many farmers in the field of spatial and sequential combinations of species and varieties is an essential prerequisite to the design of ecologically intensive cropping systems (Valet 1999, 2007). It is however not really taken into account in conventional models, which, for the most part, are inherited approaches on monospecies cover, keeping to a number of species, spatial conditions for crop establishment and limited bioregulation processes (Malézieux et al. 2009). Although they provide many useful concepts and supports to the development of the next generation of models for the simulation of multi-species systems, progress is expected in the design of plot scenes (Plate 12) allowing to simulate the diversity of spatio-temporal combinations of mixtures of species and varieties and their coupling with simulation models of multispecies systems operation (to be designed in 1D, 2D or 3D depending on configuration).

A new generation of models based on these principles would allow searching of the most complementary spatio-temporal combinations by optimization of niche differentiation between species on a multi-criteria basis integrating agronomic, environmental and technical characteristics just as well.

As an example, for multilayered plant communities, the Hi-sAFe model (Dupraz et al. 2004) allows an integration of competition relationships for water, light and nitrogen between individuals belonging to different species and layers. It is spatialized

Plate 12 Samples of multi-species systems establishment simulated with the MIX-Sim platform developed under Open-Alea) (**a**), structure in alternate rows, (**b**) alternating between and on rows, (**c**) mixed structure creole-type garden and Bamileke and Bamum fields (Ozier-Lafontaine et al. 1998; Valet 1968)

in 3D for both the aerial and underground parts. It allows reporting on the following major functional traits:

- Phenological discrepancies between species.
- Architectural plasticities of aerial and underground parts.
- Species skills of mixed species in the competition for water and nitrogen.

Hi-sAFe thus allows, through a parallel simulation of the mixed system and the pure systems, to calculate the studied mixed cropping LER. The number of simulated mixed species depends on the ability to set up the species. Nevertheless, Hi-sAFe is currently limited to temperate crops and trees, and its tropicalization will help it evolve into a reference tool for multilayered multi-species cropping systems. With such a tool, it becomes possible to investigate the optimization of ecological niches in relation to production (yield), simultaneously taking into account of technical constraints such as the possibility of spending between the rows with a tractor, or the return of a stock of water, nitrogen and organic matter necessary for the resumption of the following crop. In future versions, Hi-sAFe could therefore constitute a reference model to approach resource sharing. The challenge is to predict and understand the effectiveness of mixed cropping, and to explore innovative technical arrangements to operate these systems. This could lead to optimize the choices and combinations of species in relation to objectives of crop protection. One of the advantages of such a modelling platform will be to highlight emerging species properties of mixed systems, properties that are not readily accessible for observation. Without prejudging the outcome of this work, we propose a list of emerging properties whose highlighting and quantifying would result in real scientific advances:

- Importance of rare events (such as drought) on the functioning of mixed species, and the resilience of these systems.
- Terms and conditions of the expression of facilitative relationships between species.
- Importance of night-time redistributions of water by the root system of trees on the functioning of mixed systems (hydraulic lift).

- Reactivation of biogeochemical cycles by deep colonization of the soil with plant roots induced by interspecies competitions.
- Impact on the carbon balance by deep burial of carbon from the root turn-over of trees.

The mobilization of concepts allowing the integration of the functional groups involved at different levels of regulation, including that of the food webs is another important issue worth developing in future models (see the chapter by Clermont-Dauphin et al., this volume).

The concept of functional traits derived from ecology-trait-based ecology (Brussaard et al. 2010; Lavorel and Garnier 2002), yet little used in agronomy, could be a useful medium for this reflection. One of the important issues associated with the possible uses of functional traits for crop species is that of the transition from the individual to population. In ecology, functional traits are considered at the level of the individual and its interactions with other components. In agronomy, the notion of population is the one that dominates through its responses to changes in the environment and practices. The issue of the robustness of a functional trait and its ability to become more widespread will thus be crucial to assist the design of innovative cropping systems via a selection of species based on expected services and via the terms and conditions of their integration in the agroecosystem. Benchmarks will have to be produced around the calibration of functional traits from ad hoc devices and research protocols in order to facilitate their widespread use.

Finally, this new generation of models must match a renewed experimental approach, allowing to experiment with network interactions. For example, when we will focus on the regulation of a bio-aggressor where regulations of various kinds, direct (trophic, chemical i.e. allelopathic) or indirect (enhanced plant vigour through nutrition) are involved, it will be necessary to consider mechanisms for tackling with the synergies involved. Conducting trials allowing dealing with integrated issues of agro-ecosystem functioning is required. The example of "*Biodiversity experiment*" or Jena experiment (http://www.ufz.de/Ratio.php?en=7000), which studies the interactions between the diversity of meadow species and ecosystem processes by focusing on biogeochemical cycles and trophic interactions, is therefore highly instructive.

Contribution of Concepts from Thermodynamics to the Modeling and the Development of Indicators

The flow of energy in environmentally intensive systems and the way in which technical choices affect its conservation/degradation will be a central issue for the design of innovative environmentally intensive systems. Besides the concepts of ecology of populations and communities drawn from the evolutionary biology, another more recent theoretical approach has taken place around thermodynamic ecology (Odum 1975, 1988, 1995; Odum and Odum 2003), which provides structuring bases for the energetic analysis of the systems. A major interest is the use of universal variables such as the *eMergy* for coupling and analysing processes and compartments of different nature. This approach based on thermodynamic analysis could be decisive, both in the comparative assessment of the energy efficiency of environmentally intensive systems in different technical scenarios, as in the approach to the scaling change between compartments or spheres of different nature (scale independent concept). On the output, indicators for the design of environmentally intensive systems could also be provided to supplement usefully more conventional indicators of diversity, productivity and efficiency, required for the assessment of these ecologically intensive systems (Monzote et al. 2009).

Development of Traditional Ecological and Innovative Modern Knowledge

In recent years, numerous studies have fuelled the debate on the design of new farming systems and agronomic engineering sensu *lato* (Meynard and Sébillotte 1989). This directive is therefore based on a disciplinary field where agronomy, as a discipline for action, has managed to structure its foundations and develop its concepts in agreement with the new specifications of agriculture for the design of innovative cropping systems (Doré et al. 2006). However, compared to conventional systems, the higher complexity of multispecies systems (number of species, stand structure, biological interactions and regulations,…) creates additional difficulties in the integration process. Thus, apart from the development of the culture of monitoring, testing and co-designing of cropping systems, the richness of the expert farmers' empirical knowledge will have to be properly mobilized to develop solutions (Valet 2007). Environmental practices thus make an invaluable benchmark for promoting the principles of an ecological intensification (Gliesmann 2001; Griffon 2006).

The multi-species systems designed to support productivity in the long term have been widely used in traditional agricultures, particularly in the tropics. The bottom-up approach with *feedback "farmers' Knowledge-Ecosystems-multidisciplinary research-Ecosystems-farmers' Knowledge"* offers a practical framework for the integration of farming practices, too often ignored, in a perspective of sustainable improvement (Fig. 21).

Many agronomic trials conducted in tropical areas, at a time when they were given less interest, should be revisited in order to capitalize and develop the lessons learned from the diversity of traditional cultural combinations and the terms and conditions of their implementation into innovative crop systems. This should take into account all the aspects covered by these combinations and not stop at the only available techniques which are often added together, and assessed for yield only, rather than combined in an integrated approach (Lançon et al. 2007). One of the priorities is to bring together dispersed knowledge (often in the form of grey literature) based on meta-analysis to provide quantitative references and guidelines and the development of expert systems. These approaches will be structured around a typology of agrosystems and geographical and socio-economic contexts; they will also have to consider the modern variants of ecologically intensive systems such as Direct Seeding Mulch-based cropping systems, like SAMBAs which decrease the nutrients leaching and more recently permaculture (Gliessman 1997).

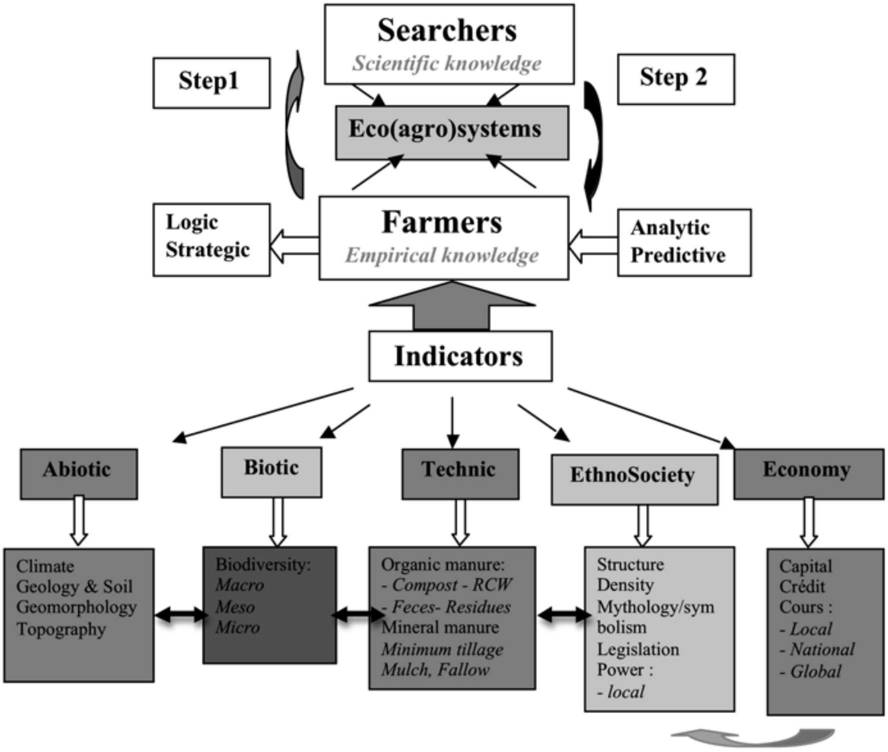


Fig. 21 Illustration of an integrative approach combining in an interactive loop 'farmers' know-how- knowledge of ecosystems – multidisciplinary research- innovation'

Conclusion

Traditional mixed cropping, mostly practiced in the tropical zone, and long marginalized compared to the conventional model of intensification, is now experiencing a strong revival. The environmental, productivity and resilience limits imposed by the intensified monoculture and denounced in 1975 by Trenbath *'Diversify or be damned'*, are now reaching a critical threshold requiring a new and genuine technological revolution in systems engineering and modes of production. The FAO calls for an agricultural paradigm shift *'The present paradigm of intensive crop production cannot meet the challenges of the new millennium. In order to grow, agriculture must learn to save'* Shivaji Pandey, Head of FAO's Plant Production and Protection Division, explained that *'The Green Revolution brought agriculture to the level where crop productivity growth rates are declining everywhere … the soil, the water, the friendly pests, have to be saved for us to produce that extra food by 2050'*. The assessment of agricultural systems will no longer rely exclusively on the basis of the food they provide, but also on their ability to limit the impact on the environment as well as their contribution to the mitigation and adaptation to the climate change. To support this paradigm shift, adequate agricultural policies must be developed (Griffon 2007; Malézieux 2012).

In this chapter, the results obtained on the diversity of multi-species systems, from the plot to the territory scale, covering a long period from the 1960s up to now, are a significant credit to the knowledge of traditional practices and performances permitted by these very adaptative systems in peasant tropical or Sudan-Sahelian farms. The work presented shows the comparative advantages permitted by the ecosystem services provided by mixed cropping, resulting in (i) yields, often significantly higher than in monocultures, (ii) a decrease by 2 of the use of mineral and organic fertilizers, (iii) effective alternative to biocidal products, (iv) very significant water saving opportunities and also a significant saving of energy, (v) a better use of mountain soils and (vi) a more pragmatic use of time.

From a general point of view, the scarcity of results on the assessment of the cost/benefit of ecosystem services, demonstrates the difficulty of establishing the global accounts of ecosystems including resources, flows, services, stocks, integrated in the SEEA. The development of original indicators, such as the IER and the SEEA provides an initial assessment of the free functions of ecosystem services, performed with less investment and annual expenditure, and leading to a significant reduction in the risks of soil degradation, water and food pollution, due to the reduction of inputs.

The relevance of the economic assessment of the environment is emphasized by many economists (Brahic and Terreaux 2009; Rotillon 2005). The calculations carried out were limited to the monetization of the most accessible ecosystem services. No predictive calculations were considered in terms of individual well-being and societal benefits. However, the financial statements provided by ecosystem services demonstrate the need to change behaviour to protect the environment, to imagine other modes of growth, and therefore, to choose an ecodevelopment protecting the agro(eco) systems. The estimate of the profits generated by all of the services is not easy to realize. It does not enter into the subject of this review, but it would deserve a species development.

The development of an agro-ecological engineering, and specially the expected progress in the integration of ecological concepts for analysis, assessment and conduct of multispecies systems, has highlighted the need for a close cooperation between "*expert*" and "*empirical*" knowledge. In their analysis of the new '*paradigm of ecological intensification*' Doré et al. (2006) recommend some changes in attitudes breaking with the conventional view of agronomic research in order to produce knowledge and new learning for the benefit of the design of innovative agroecosystems. The emergence of these '*new avenues*' poses the challenge of building an 'actionable' knowledge to the benefit of an engineering of ecologically intensive agrosystems. This encourages us to set a new perspective of our reasoning to develop innovative concepts, it also goes through a renewal of academic approaches at different levels of physical (m^2, plot, watershed, small area: Pavé 1997; Van Duivenbooden et al. 2000; Valet 1999, 2008) and cognitive perception. This necessarily implies:

(i) The construction of a frame breaking with the classic conventional agronomic thought, backed by new cognitive requirements, including the ability to cope with technological and eco-sociological breakthroughs: adapting collective knowledge, sharing with unusual partners, tackling cloudy even contradictory logics, enriching the logic by the intuitive and the sensitive, facing the unimaginable.

(ii) The promotion of '*amazing*' tactics as those consisting, for example, in engaging in multidisciplinary teams (peasant, cook, healer, sorcerer, nutritionists, researchers, etc.), sharing unusual converging values, abandoning learned beliefs and certainties, revisiting the traditional unknown, detecting the unsuspected '*sleeper variants*', having a critical follow-up of methods/results in a group.

(iii) While developing innovative methods based on both the empirical discovery of traditional farming *empirical knowledge*, as close as possible to the actors, while applying academic knowledge to their understanding, identifying new contingencies, which requires a renewed perspective of rational analysis grids, facing a '*chaotic breakup*' along with the creation of new scientific trainings.

This can be established by encouraging constant *feedback* between the farmers' innovative, logical, strategic, traditional ***'empirical knowledge***', and the scientists' analytical and predictive '***expert knowledge***' (Valet 1976; Valet and Motelica-Heino 2010) (Fig. 21).

Thus, faced with new and old challenges that agriculture, livestock and forest must meet, two schools of thought are emerging. The first, a reasoned conservative farming is to explore new ways of conceptual agroecosystems proposing to mimic the structure of natural ecosystems, forest and meadow, through the Direct Seedling Mulch-based cropping systems, or the Agroforestry Intercropping Systems (AIS) with a very limited number of species even under excellent soil and climatic conditions (Jackson 2002; Malézieux and Moustier 2005; Séguy et al. 2008). The second, an agriculture of maximization, aimed at strengthening traditional mixed cropping (at least 47 species) and innovative practices with new biophysical techniques to achieve a more efficient and sustainable resilience to climate change, demographic increase and liberalism, decline in water and nutritional resource and with the role played by the ecological processes of these combinations (Autfray 2005; Baldy 1963; Baldy and Stigter 1997; Baker and Norman 1975; Charreau 1972; Dugué 1998; Dupriez and de Leener 2003; Dupriez 1980a, b, 2006; Jagoret et al. 2012; Le 2002; Salez 1990; Trenbath 1975; Valet 1968, 1976, 2007; Wilken 1972).

The recurrence of food crises in the world has contributed to a shift in thinking about emergency and development. The model that separates development – to prevent crises – from humanitarian – to solve them – now seems outdated. For several decades, food security policies have focused on increasing agricultural productivity, but in front of the relative failure of these policies, demonstrated by repeated food crises, the need for a broader approach has emerged so as to deal with all aspects of vulnerability i.e. economic, but also social, climatic, … (Oxfam 2011). We are going to enter a new stage: not only that of the 'major risk' but rather that of the 'mega-shocks', likely to operate global destruction. Therefore, the very concept of temporary crisis and shock needs to be readjusted, by addressing the root and chronic causes of vulnerability. Since 2005, the Hyogo Framework For Action, a strategic 10-year plan, developed by UNISDR (United Nations International Strategy for Disaster Reduction), has proposed to '*build the resilience of nations and communities facing disasters*' (Inter réseaux 2013).

Resilience was introduced in thinking on development and adaptation to climate change through Disaster Risk Reduction. The aim is to invent new *'amazing and miraculous'* solutions to address the fundamental changes that lead to the new paradigms presented, and offer open and creative concepts shared among the farmers and the scientists to manage these crises, and prevent any collapse. The global conversion to an agro-ecological agriculture is neither a utopia nor a return to the past, but rather the best road to meet future food challenges. This type of agriculture would allow small producers (more than 500 million family farms in the World: Planète 2012) to break the vicious cycle of poverty and dependence on large petrochemical companies, and live from their work without having to go into exile.

Although the idea that '*intercropping was only for peasant farming and has no place in modern agriculture*', (Tardieu 1970) has persisted for a long time among researchers and developers, it appears more than ever that 'in many areas of the world, traditional farmers developed or inherited complex farming systems in the form of poly-cultures that were well adapted to the local conditions and helped them to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan 1995). These practices, thus generally more efficient than the high-intensity agricultural systems, highlight the '*agricultural engineering*' developed over centuries by the so-called 'primitive' peoples. Hence, traditional and innovative multispecies cropping systems could turn out to be a modern one.

Glossary

ANR	Assisted Natural Regeneration
CA	Conservation Agriculture
CFA	Franc des Colonies Françaises d'Afrique
CIRAD	Centre International de Recherche Agronomique et de Développement
DER	Density Equivalent Ratio
DMC	Direct Seeding Mulch-Based Cropping System
FAO	Food and Agriculture Organization
FEER	Fertility Efficiency Equivalent Ratio
ESS	EcoSystemic Services
ICS	Inter Cropping Systems
ICS	Inter Cultural System
IER	Income Equivalent Ratio
IRRI	International Rice Research Institute
Kram	Run off Coefficient
LAI	Leaf Area Index
LAR	Leaf Area Ratio

LER	Land Equivalent Ratio
MCS	Multi-species Cropping Systems
MEA	Millennium Ecosystem Assessment
MOS	Matter Organic Sum
N	Nitrogen
OC	Organic Carbon
OM	Organic Matter
P	Phosphorus
RCW	Rameal Chipped Wood
RER	Root Equivalent Ratio
TE	Transpiration over Evaporation
UNISDR	United Nations International Strategy for Disaster Reduction
USAID	United States Agency for International Development
WuEER	Water use Efficiency Equivalent Ratio

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