Mango-based orchards in Senegal: diversity of design and management patterns

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Abstract – Introduction. Mango-based orchards in Senegal occur in a large diversity of cropping systems, but few typologies of these systems exist and none are associated with their comprehensive and quantitative analysis. In this study we defined and characterized the typology of these systems based on a quantitative assessment of their planting design, management, vegetative state, hedgerow structure and infestation by a major pest of mango, the *Bactrocera invadens* fly. **Materials and methods**. Multivariate analysis and clustering methods were applied to data from 64 mango-based orchards and their surrounding hedgerows sampled in the Dakar and Thiès regions, in Senegal. **Results and discussion**. Four types of cropping systems were identified according to orchard design and management patterns: (1) 'No-input mango diversified orchards', (2) 'Low-input mango orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards'. Orchard characteristics varied among these patterns. For instance, vegetation was dense and homogeneous in system 1, and the mortality rate of trees was high in system 2 but low in system 3. Orchards of systems 3 and 4 were mostly associated with hedgerows with, respectively, boundary-marking and defensive species. Lastly, the number of *B. invadens* flies was high in orchards of system 4, whereas it was low in those of system 2. **Conclusion**. The diversity of mango-based cropping systems in Senegal is now well described and quantified. This characterization is a preliminary step that is essential for further studies aiming to improve these systems.

Senegal / *Mangifera indica* / fruit trees / orchards / typology / design / crop management / *Bactrocera invadens* / hedges / multivariate analysis

Vergers à base de manguiers au Sénégal : diversité des modèles de conception et de gestion.

Résumé – Introduction. Les vergers à base de manguiers au Sénégal se rencontrent sous une grande diversité de systèmes de culture. Cependant, peu de typologies de ces systèmes existent et aucunes ne sont associées à leur analyse exhaustive et quantitative. Dans cette étude, nous avons défini et caractérisé la typologie de ces systèmes sur la base d'une évaluation quantitative de leur conception, de leur gestion, de leur état végétatif, de la structure de leurs haies et de leur infestation par un ravageur important de la mangue, la mouche *Bactrocera invadens*. **Matériel et méthodes**. Des méthodes d'analyse multivariée et de classification ont été appliquées sur des données provenant de 64 vergers à base de manguiers et de leurs haies environnantes, échantillonnés dans les régions de Dakar et de Thiès, au Sénégal. **Résultats et discussion**. Quatre types de systèmes de culture ont été identifiés selon des modèles de conception et de gestion du verger : (1) « Vergers de manguiers diversifiés sans intrants », (2) « Vergers de manguiers à faible intrants », (3) « Vergers à *Citrus* prédominants avec niveau intermédiaire d'intrants » et (4) « Grands vergers de manguiers ou de *Citrus* prédominants avec niveau intermédiaire d'intrants ». Les caractéristiques des vergers ont varié entre ces types de systèmes. Par exemple, la végétation était dense et homogène dans le système 1. Le taux de mortalité des arbres était élevé dans le système 2 mais faible dans le système 3. Les vergers des systèmes 3 et 4 étaient principalement associés à des haies avec respectivement des espèces de bornage et des espèces défensives. Enfin, le nombre de mouches *B. invadens* était élevé dans les vergers du système 4, alors qu'il était faible dans ceux du système 2. **Conclusion**. La diversité des systèmes de culture à base de manguiers au Sénégal est maintenant bien décrite et quantifiée. Cette caractérisation est une étape préliminaire indispensable pour poursuivre des études visant à améliorer ces systèmes.

Sénégal / *Mangifera indica* / arbre fruitier / verger / typologie / conception / conduite de la culture / *Bactrocera invadens* / haie / analyse multivariée

1. Introduction

Cultivation of mangos (*Mangifera indica* L.) has expanded in West Africa throughout the twentieth century, for local consumption, national or regional markets and intercontinental exports [1, 2]. The annual Senegalese production has reached 100,000 t[1] [2]. Although intercontinental exports represent a small proportion of the production, their economic and social impact is very high [1, 2]. During the last ten years, Senegalese exports (mostly to Europe [2, 3]) have increased, ranging up to more than 8,000 t. However, export volumes are unstable[1]. The main reasons for this are due to competition with other production origins and recurrent problems of fruit quality due to fungal diseases and fruit flies [2, 3]. Several local fruit fly species are endemic pests of mango. However, during the last ten years, a new invasive species, *Bactrocera invadens* [4–6], has become one of the most damaging pests of mango [2]. Mango malformation disease, which has recently been reported in southern Senegal [7], could become another serious threat to mango production. The mango sector in Senegal has high development potential, but an improvement of the mango-based cropping systems is needed to overcome their high production and quality irregularities. Mango-based cropping systems in West African countries are highly varied, from gatherer and pluri-specific orchards to intensive mono-specific orchards [2, 6, 8–10]. Even though this diversity is generally known, a thorough knowledge of the current systems and their functioning is still lacking for stakeholders' concern with improvement of Senegalese mango production.

The agronomic practices and the varietal composition of orchards largely contribute to the diversity of mango cropping systems observed in West Africa [8]. Most studies carried out on mango production in Africa focus only on one element of the cropping system, such as varietal choice, irrigation [11, 12], thinning [13] or pest control [14–16], and on its impact on mango trees. For instance, irrigation was shown to influence vegetative growth of mango trees [12]. A typological approach is often used in studies that aim to grasp the diversity of cropping systems. It has been used in horticultural systems for cacao-based agroforests, apple, banana, citrus production, etc. [17–20]. Regarding mango production, only some studies have outlined system characterizations, which focused primarily on the level of intensification of cropping systems [6, 9] and the composition of the orchards [10]. Vayssières *et al.* identified four types of systems in West Africa: the "gatherer production system", "production system under improvement", "more intensive production system" and "large industrialized orchards" [9]. In two other studies carried out in the Niayes region in Senegal, Vayssières *et al.* simply differentiated between "mixed (pluri-specific)" and "homogeneous (mono-specific) orchards" [6], while Ndiaye *et al.* differentiated between "traditional" and "modern (intensive) orchards" [10]. However, these approaches were not based on a comprehensive and quantitative analysis of both the orchard designs issuing from farmers' planting choices and the agricultural practices the farmers use for current orchard management. In addition, they did not take into account other elements of system functioning, such as the orchard vegetative state, which could be related to technical choices of orchard design and management.

Orchards can be enclosed with hedgerows, which is another element of farmers' technical choices. Their roles and interactions with the neighboring orchards have been studied a lot in developed countries, but very little in the case of Senegalese orchards. Hedgerows have different functions: protection against marauding and domestic or wandering animals, wind-break, and supply of edible seeds, fruits, firewood or stakes [8]. We suggest that the presence of hedgerows and their structural characteristics could be related to technical choices of orchard design and management as part of farmers' overall production strategy.

Hedgerows can have an effect on the biodiversity and abundance of arthropods in

[1] Anon., FAOSTAT, Food and Agriculture Organization of the United Nations, accessed 08 Oct 2012 at: http://faostat.fao.org/.

orchards [21, 22]. For instance, they can affect the spatial distribution of arthropod communities in pear orchards [23], reduce populations of codling moth (*Cydia pomonella*) in apple orchards [24], and reduce infestation by fruit flies in mango orchards [25]. The vegetation-based structure of the orchard provides perennial and multi-strata habitats that can also contribute to maintaining diversified arthropod populations [22]. For instance, leaf litter can increase the biodiversity of arthropods [26–28]. Fruit trees in and around orchards provide alternative oviposition substrates for fruit flies. However, the amount and quality of supplied substrates are related to fruit tree species and mango cultivars since they show differences in fruit maturation periods as well as varying levels of susceptibility to fruit flies [10]. Additionally, the hedgerow and the density of the tree canopy are both factors affecting the orchard's microclimate, such as shading, light intensity, ambient temperatures and relative humidity, known to affect fruit fly distribution [25], physiological disorders and fungal diseases (*e.g.*, anthracnose) [8]. Finally, it is likely that the orchard's phytosanitary state, including orchard infestation by fruit flies, varies between the cropping systems, depending not only on pest control practices but also on the structural composition and vegetative state of both the orchards and the hedgerows.

Based on these main technical components, we chose as a first objective to characterize the range of diversity of Senegalese mango-based cropping systems regarding each element of the system (*i.e.*, orchard planting design, current orchard management, orchard vegetative state, orchard infestation by *B. invadens* and hedgerow structure) independently. The second objective was to classify these systems into groups with similar patterns regarding technical choices of orchard design and management. The third objective was to evaluate to what extent the characteristics of the systems relating to the orchard vegetative state, hedgerow structure and orchard infestation by *B. invadens* depend on these design and management patterns.

2. Materials and methods

2.1. Study area and orchard sampling

The study was carried out in the Dakar and Thiès regions, in West Senegal. These regions are characterized by ferralic arenosols and a Sahelian climate with unimodal rainfall from July to September (between 600 mm and 750 mm per year between 2008 and 2012). The favorable climate mitigated by a cool and humid trade wind during the hot season makes these two regions the major fruit and vegetable production areas of Senegal. Within the study area, sixty-four orchards consisting of at least 5% mango trees and which had easy access were randomly sampled around four localities: 'Notto', 'Sébikotane', 'Pout' and 'Pékou'. In our study we defined cropping systems (sometimes obviously assimilated as 'orchards') as the orchards *stricto sensu* along with pastures and vegetable crops cultivated in the orchards and their surrounding hedgerows.

2.2. Data collection

The cropping systems were described with 42 variables. The variables were classified into five groups (*table I*). All 64 cropping systems were described with variables regarding 'orchard design', 'orchard management' and 'orchard vegetative state' groups. Variables of the 'orchard infestation' and 'hedgerow structure' groups were available only on a sub-sample of 54 cropping systems that corresponds to the orchards sampled around 'Notto', 'Sebikotane' and 'Pout'. The data set for the 42 variables was collected from April to September 2010.

2.2.1. Variables of the 'orchard design' group

The variables of the 'orchard design' group describe the current structural design of the orchard *stricto sensu* that resulted from the planting choices of the farmer for trees (*table Ia*). Orchards were located on satellite images dating from 2002 to 2009 and their acreages were estimated by image processing. Other variables were calculated from measurements made individually on

Table I.
Variables and sub-groups of variables used to characterize the cropping systems: definition, mean, standard deviation, minimal (Min) and maximal (Max) values calculated on the orchard sample (*n* stands for the number of orchards in the sample).

a) Group 1. Orchard design (*n* = 64)

Sub-groups	Variables	Definition (unit)	Mean ± SD	[Min–Max]
Acreage	Acreage	Orchard acreage (ha)	3.70 ± 4.48	[0.30–22.9]
Density	Density	Mean local planting density of trees (ha^{-1}) [(a)]	455 ± 356	[140–2387]
Density CV	Density CV	Coef. of variation of the local planting densities of trees [(a)]	0.54 ± 0.45	[0–1.93]
Species	Species	Number of tree species	3.67 ± 2.41	[1–10]
Cultivar	Cultivar	Number of mango cultivars	2.25 ± 1.07	[1–5]
%Species		Orchard composition of tree species [(a)]		
	Mango	% of trees of mango species	64.3 ± 34.7	[5–100]
	Orange	% of trees of orange species	7.9 ± 12.0	[0–52]
	Grapefruit	% of trees of grapefruit species	11.2 ± 19.9	[0–94]
	Mandarin	% of trees of mandarin species	10.8 ± 15.2	[0–59]
	Lemon	% of trees of lemon species	1.8 ± 4.2	[0–25]
	Papaya	% of trees of papaya species	1.7 ± 4.7	[0–27]
	Guava	% of trees of guava species	0.3 ± 1.0	[0–5]
	OtherFruit	% of trees of less frequent species [(b)]	1.8 ± 4.7	[0–29]
%Cultivar		Orchard composition of mango tree cultivars [(a)]		
	Kent	% of mango trees of cv. Kent	58.5 ± 37.4	[0–100]
	Keitt	% of mango trees of cv. Keitt	5.4 ± 14.6	[0–68]
	BDH	% of mango trees of cv. Boucodiékhal (BDH)	27.8 ± 36.9	[0–100]
	DBG	% of mango trees of cv. Dieg bou gatt (DBG)	2.5 ± 7.3	[0–50]
	Sewe	% of mango trees of cv. Séwé	2.6 ± 6.3	[0–24]
	OtherMango	% of mango trees of less frequent cultivars [(b)]	3.2 ± 13.3	[0–100]

[(a)] Variable definition and calculation are given in *Appendix A.*
[(b)] Less frequent mango cultivars are 'Amélie', 'Greffal', 'Papaye' and 'Pêche'; less frequent tree species are avocado, cashew, banana, attie, soursop, sapodilllo, kumquat, cherry, coconut and palm trees.

Table I.
Continued.

b) Group 2. Orchard management (n = 64) [c]

Sub-groups	Variables	Definition (unit)	Mean ± SD	[Min–Max]
Pasture	Pasture	Level of secondary use of the orchard for pasture by ruminants	0.72 ± 0.88	[0–2]
OtherCrop	OtherCrop	Level of secondary use of the orchard for cultivation of associated food or vegetable crops	0.59 ± 0.50	[0–1]
Irrigation	Irrigation	Irrigation intensity based on the amount of water supplied and mechanization level	0.95 ± 0.80	[0–2]
SoilCare	SoilCare	Shallow tillage and/or mechanical weeding for soil care	0.92 ± 0.28	[0–1]
Pesticide	Pesticide	Application frequency of natural or synthetic pesticides	1.29 ± 1.10	[0–3]
Fertilization	Fertilization	Fertilization intensity based on the amount and form of N supplied	1.52 ± 1.13	[0–3]
FruitPicking	FruitPicking	Picking up frequency of fallen fruits for preventive fruit fly control	0.56 ± 0.70	[0–2]

[c] Modalities of the variables that describe the level of use of the management practices:
• Pasture: 0, not used; 1, occasional; 2, frequent (daily to once a week).
• OtherCrop: 0, not used; 1, used (cultivated food and vegetable crops, *e.g.*, maize, cowpea, onion, tomato, cabbage, chili pepper, etc.).
• Irrigation: 0, not used; 1, moderate (≤ 200 L per tree per week, manual irrigation only); 2, high (> 200 L per tree per week, manual or mechanized drip or micro-spray irrigation).
• SoilCare: 0: not used; 1, used.
• Pesticides: 0, not used; 1, occasional (1 to 2 times a year); 2, regular (3 to 5 times a year); 3, frequent (> 5 times a year).
• Fertilization: 0, not used; 1, moderate (< 0.5 kg N per tree per year) with organic N only; 2, moderate (< 0.5 kg N per tree per year) with both organic and chemical N; 3, high (≥ 0.5 kg N per tree per year).
• FruitPicking: 0, not used; 1, occasional (≤ once a week); 2, frequent (> once a week).

c) Group 3. Orchard vegetative state (n = 64) [d]

Sub-groups	Variables	Definition (unit)	Mean ± SD	[Min–Max]
Mortality	Mortality	Mortality rate of trees	0.16 ± 0.19	[0–0.76]
Height	Height	Mean height of living trees (m)	4.83 ± 2.00	[1.32–10.6]
Vigor	Vigor	Mean vigor index of living trees	2.89 ± 0.55	[1.82–4.75]
Cover	Cover	Mean local ground covering of trees (%) [a]	31.0 ± 17.2	[4.0–83.1]
Litter	Litter	Mean litter abundance index of trees	1.26 ± 0.37	[0.48–2.18]
HeightCV	HeightCV	Coef. of variation of the heights of living trees	0.48 ± 0.24	[0.17–1.30]
CoverCV	CoverCV	Coef. of variation of the local ground coverings of trees [a]	1.13 ± 0.58	[0.34–3.55]

[a] Variable definition and calculation are given in *Appendix A*.
[d] Modalities of the variables that describe the tree vigor and litter abundance:
• Vigor for living trees: 1, tree is almost dead with no leaves; 2, much of the branches are dried and without leaves, foliage is partly brown; 3, some branches are dried and without leaves, foliage is green; 4, some branches are dried at their end, foliage is green; 5, no dried branches, foliage is very green and bright.
• Litter: 0, low (< 10% of ground covered by leaves and pruning residues); 1, moderate (10–50%); 2, high (50–90%); 3, very high (90–100%).

Table I.
Continued.

d) Group 4. Orchard infestation (*n* = 54)

Sub-groups	Variables	Definition (unit)	Mean ± SD	[Min–Max]
FruitFly	FruitFly	Mean number (× 10^{-3}) of males of *Bactrocera invadens* fly species trapped per pheromone trap during 20 consecutive weeks	7.50 ± 3.39	[1.09–17.8]

e) Group 5. Hedgerow structure (*n* = 54)

Sub-groups	Variables	Definition (unit)	Mean ± SD	[Min–Max]
Hedge	Hedge	% of orchard perimeter planted with hedgerow	72.3 ± 33.4	[0–100]
HedgeSpecies	HedgeSpecies	Number of tree and shrub species in the hedgerow	6.22 ± 3.72	[0–15]
HedgeCover	HedgeCover	Total hedgerow ground covering (%) by trees and shrubs [(a)]	71.3 ± 41.6	[0–156]
%Use		Composition of hedgerow ground covering in species' utilities [(a)]		
	Use_1	% of total hedgerow ground covering by boundary-marking species	39.3 ± 33.4	[0–100]
	Use_2	% of total hedgerow ground covering by defensive species	38.0 ± 32.6	[0–95]
	Use_3	% of total hedgerow ground covering by fuel wood or timber species	17.0 ± 15.5	[0–71]
	Use_4	% of total hedgerow ground covering by productive species (food, dyeing or medical use)	2.4 ± 4.4	[0–14]
	Use_5	% of total hedgerow ground covering by fruit species	3.5 ± 6.0	[0–25]

[(a)] Variable definition and calculation are given in *Appendix A.*

all the trees of the orchard (whether they be living or dead), or at the most 100 trees randomly sampled within the orchard if the number of trees exceeded 100.

2.2.2. Variables of the 'orchard management' group

The variables of the 'orchard management' group describe annual management practices applied by the farmer for the maintenance of the orchard (*table Ib*). They were defined as qualitative ordinal variables whose number of modalities varied from two to four. As a rule, the higher the modality value, the higher the level of use of the practice. A modality value of '0' means that the practice is not applied. Modalities were defined and values assigned to orchards based on data collected from farmer interviews. A variable accounting for tree pruning was listed in the questionnaire but it was not taken into account in the analysis as all the farmers answered they did it.

2.2.3. Variables of the 'orchard vegetative state' group

The variables of the 'orchard vegetative state' group describe the current state of trees and vegetation background in the orchard (*table Ic*). They were calculated from measurements made individually on the tree scale on the sample of trees defined in section 2.2.1. For the vigor and height variables, only living trees were considered. Local ground covering describes the proportion of ground area equal to the inverse of the local planting density of a tree that is covered by the vertical projection of the tree crown. Litter consists of leaves and pruning residues on the ground. Tree vigor and litter abundance indices were defined as ordinal variables with, respectively, five and four modalities. As a rule, the higher the modality value, the higher the tree vigor or litter abundance. Modality values were assigned to trees based on visual estimates.

2.2.4. Variable of the 'orchard infestation' group

The variable of the 'orchard infestation' group describes the relative abundance of fruit flies in the orchards during the rainy season for the most abundant fly species in the study area (data not shown), *Bactrocera invadens* (*table Id*). Data were collected using pheromone Tephri-traps following the protocol describe by Vayssières *et al.* [4]. Traps contained methyl-eugenol, a parapheromone lure that attracts males of the *B. invadens* fly species. There were about three traps per orchard (according to the orchard size, this number could, however, vary from two up to six). Traps were suspended on trees and set up at a 40-m distance from each other. They were monitored weekly. At each monitoring date, the captured flies were counted and removed from the traps. The trapping period lasted 20 consecutive weeks from mid-April to September 2010. It covered almost the entire mango fruiting season [10].

2.2.5. Variables of the 'hedgerow structure' group

The variables of the 'hedgerow structure' group describe the presence, abundance and composition of the perennial part of the hedgerow surrounding the orchard (*table Ie*). They were defined based on visual estimations (*e.g.*, % of orchard perimeter planted with hedgerow) and data collected from floristic surveys of the hedgerows [29]. At the time of survey the herbaceous strata of the hedgerows was almost absent and only tree and shrub species were surveyed. Each inventoried species was classified into one of the five utility classes defined by Yossi *et al.* [30] (*table Ie*) and was assigned an average ground covering, following Bouzillé's methodology [31]. These values were used to calculate total hedgerow ground covering and hedgerow coverings according to tree and shrub species' utilities. A value of total hedgerow covering > 100% indicates a superposition of the strata.

2.3. Analytical methods

2.3.1. Characterization of the range of diversity of mango-based cropping systems

The range of diversity of the cropping systems regarding each of the five groups of variables was characterized for the entire orchard sample by using descriptive statistics and multivariate analysis. Both the 'orchard management' and 'orchard vegetative state' groups of variables were analyzed using standardized Principal Component Analysis (PCA), whereas the 'orchard design' and 'hedgerow structure' groups were analyzed using standardized Multiple Factor Analysis (MFA). The 'orchard design' and 'hedgerow structure' groups were structured into sub-groups composed of either several variables (*i.e.*, %Species, %Cultivar and %Use) or a single variable (*table Ia, Ie*). Multiple Factor Analysis is a specific method dedicated to analyzing such data sets because it balances the influence of each group of variables by taking into account the structure of the data [32, 33].

2.3.2. Building of a typology of mango-based cropping systems

A typology of the cropping systems based on orchard planting design and management practices was built using the entire orchard sample. First, a standardized Hierarchical Multiple Factor Analysis (MFAH) was performed on the variables of the 'orchard design' and 'orchard management' groups (*table Ia, Ib*). The Hierarchical Multiple Factor Analysis accounts for the hierarchical structure of the variables by balancing the influence of each group and sub-group of variables in the analysis [32]. Then, an Agglomerative Hierarchical Clustering (AHC) [33] was performed on the principal components of the MFAH, with the Euclidean distance metric and Ward's agglomeration criterion. A hierarchical tree diagram, which provides a visual condensation of the clustering results, was obtained and used to determine the level of clustering. The partition was finally consolidated with the K-means algorithm. Additionally, a typology of the hedgerows surveyed in the orchard perimeter was built using the variables of the 'hedgerow structure' group from the sub-sample of 54 orchards. The methodology described above was used, except that Agglomerative Hierarchical Clustering was performed on the principal components of a standardized Multiple Factor Analysis. The 'orchard' and 'hedgerow' clusters obtained, respectively, grouped together cropping systems presenting similar orchard design and management patterns and similar hedgerow structural patterns.

2.3.3. Characterization of the main types of mango-based cropping systems

The 'orchard' clusters obtained were described by the 'active' variables, *i.e.*, those used to perform the clustering, plus the 'illustrative' (also called 'supplementary') variables relating to the orchard vegetative state, hedgerow structural pattern (*i.e.*, the 'hedgerow' cluster) and orchard infestation by *B. invadens*. 'Illustrative' variables did not participate in the clustering but were used *a posteriori* to characterize the clusters obtained. The 'active' and 'illustrative' variables that characterize the clusters best were identified and ordered based on the v-test criterion [32, 33], with a significance level $\alpha = 0.05$. For a quantitative variable x and under the null hypothesis that the mean $(\overline{x_q})$ in cluster q is equal to the overall mean $(\bar{x})$, the v-test is calculated as follows:

$$v-test = \frac{\overline{x_q} - \overline{x}}{\sqrt{\frac{s^2}{n_q}\left(\frac{n-n_q}{n-1}\right)}},$$

where n_q denotes the number of orchards in cluster q; n, the total number of orchards; and s, the standard deviation of x for all the orchards. Number n was 64 except for the 'orchard infestation' and 'hedgerow' cluster variables, for which n was 54. The higher the absolute value of the v-test, the better the variable x characterizes the orchards in cluster q. The sign of the v-test indicates if the mean in cluster q is lower (v-test < 0) or greater (v-test > 0) than the overall mean. The v-test is also defined for categorical variables and tests the null hypothesis that the number of orchards for which the variable takes a category j is the same in cluster q (n_{jq}) and in the overall sample (n_j) (*Appendix A* in article online at www.fruits-journal.org).

All the data analysis and graphs were carried out with R software version 2.12.1 [34]. For multivariate analysis the FactoMineR package (version 1.16)[2] was used.

[2] A website is dedicated to the package: http://factominer.free.fr, accessed 08 Oct. 2012.

3. Results

3.1. Range of diversity of Senegalese mango-based cropping systems

3.1.1. Variability of the orchard planting design

The first two dimensions of the Multiple Factor Analysis explained, respectively, 26.09% and 12.86% of the total variability of the orchard planting design (*figure 1A*).

The first dimension expressed the variability that arose from planting densities, species number and composition of tree species. Overall, seventeen tree species were identified in the orchards that were sampled: mango, grapefruit, mandarin, orange, lemon, papaya and guava, plus other less frequent species (*table Ia*). There were 20 mono-specific mango orchards and 44 mixed orchards (*i.e.*, orchards with at least one non-mango tree species). Within mixed orchards, non-mango species accounted for 51.9% of the trees on average; the most abundant being grapefruit (16.3% of the trees), mandarin (15.7%) and orange (11.5%). The mean local planting density of trees varied from 140 to 2387 trees per ha but exceeded 1000 trees per ha in only two orchards. Orchards with a high proportion of mango trees, low species diversity, and low and regular planting densities were opposed to heterogeneous orchards with opposite characteristics and a high overall composition of orange, grapefruit and papaya trees.

The second dimension of the Multiple Factor Analysis expressed the variability of the orchards that arose from their acreage and composition of mango cultivars. Overall, nine cultivars were identified in the orchards that were sampled, the most frequent being Kent, Keitt, Boucodiékhal (BDH), Dieg bou gatt (DBG) and Séwé (*table I*). There were 45 orchards consisting of more than one mango cultivar; most of them had two or three different mango cultivars. Kent was the most abundant cultivar (58.5% of the mango trees), followed by BDH (27.8%) (*table I*). Orchards consisting mostly of the cultivar Kent were opposed to those which consisted mostly of cv. BDH. Orchard acreage varied from (0.3 to 23) ha but was lower than or equal to 5 ha in 80% of the orchards. Orchards with the highest acreages consisted mainly of cv. Kent. There was no correlation between acreage and specific composition in the surveyed orchards.

3.1.2. Variability of the orchard management practices

The first two dimensions of the Principal Component Analysis (PCA) explained, respectively, 41.82% and 16.19% of the total variability of the orchard management practices (*figure 1B*).

The first dimension opposed orchards with a high overall level of irrigation, fertilization, pesticide application, soil care and cultivation of associated food or vegetable crops to those with a low overall management level. Among the surveyed orchards, 66% were irrigated, 67% were treated with pesticides and 74% were fertilized. Practices for soil care were applied in almost all the orchards (*i.e.*, 92%). Food or vegetable crops were planted in association with trees in 59% of the orchards.

The second dimension of the Principal Component Analysis opposed orchards for which the frequency of pasture by ruminants was high to those for which it was not. Pasture was present in 44% of the orchards. Its occurrence seemed to be independent of the other management practices. Orchard sanitation occurred in 44% of the orchards. This practice contributed only partially to the first two PCA dimensions and orchard sanitation frequency was slightly correlated with the level of use of the other management practices.

3.1.3. Variability of the orchard vegetative state

The first two dimensions of the Principal Component Analysis explained, respectively, 45.09% and 25.42% of the total variability of the orchard vegetative state (*figure 1C*). The first dimension opposed orchards whose ground covers and heights of the trees were low and highly variable, with more homogeneous orchards with the opposite characteristics. The second dimension expressed the variability of the orchards that arose mostly from the mortality

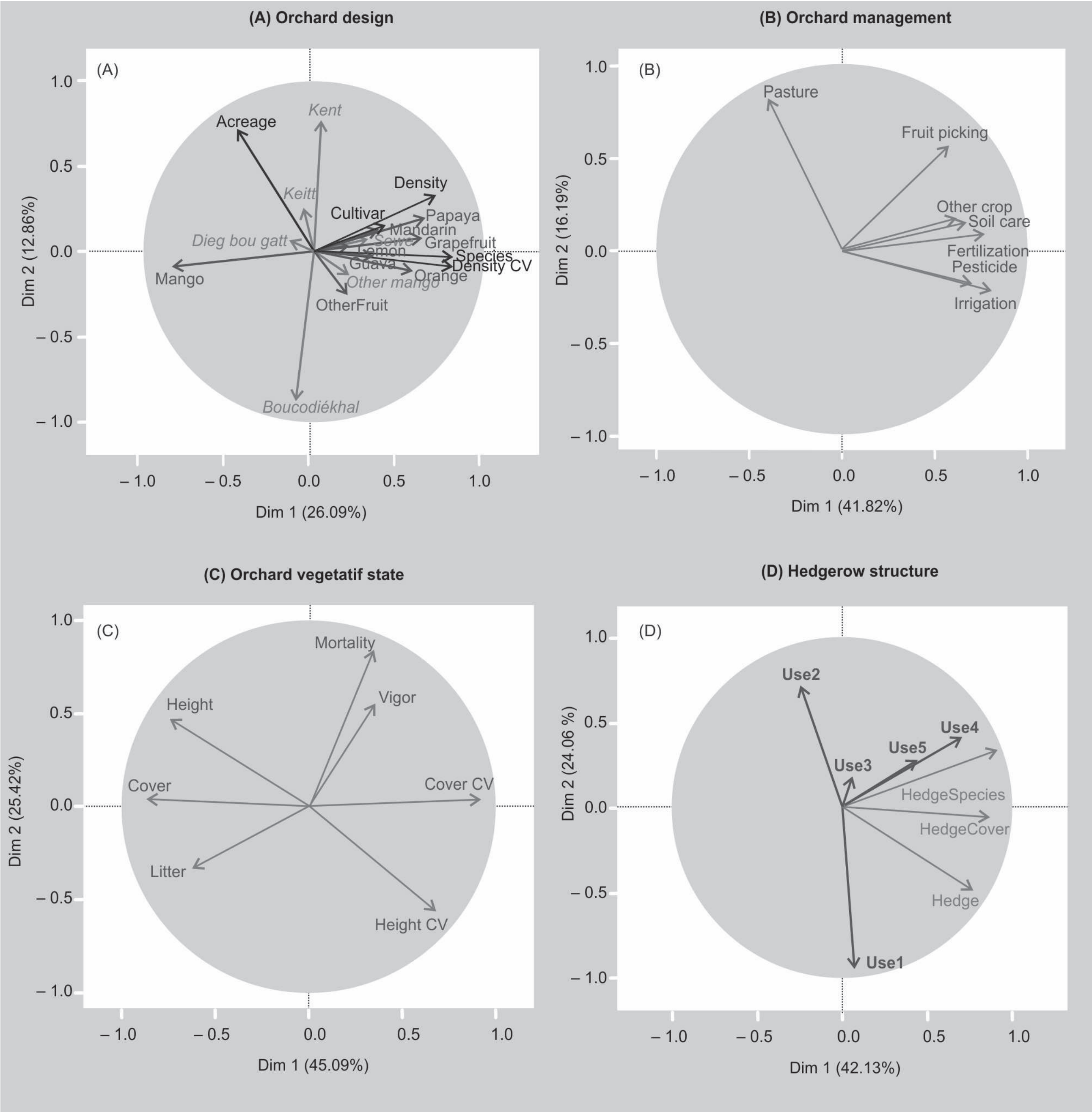

Figure 1.
Correlation plots of (A) the orchard design variables, (B) the orchard management variables, (C) the orchard vegetative state variables and (D) the hedgerow structure variables with respect to (A, D) the 1-2 Multiple Factor Analysis dimensions and (B, C) the 1-2 Principal Component Analysis dimensions.
(A) Black: sub-groups composed of a single variable; italic light gray: sub-group representing the composition of the orchard in mango tree cultivars; dark gray: sub-group representing the composition of the orchard in fruit tree species. (D) light gray: sub-groups composed of a single variable; dark gray: sub-group representing the composition of the hedgerow ground covering in tree and shrub species' utilities.

rate of the trees. Most of the orchards (*i.e.*, 89.1%) had a mortality rate lower than or equal to 0.3, but the other 10.9% had values higher than 0.5. The latter orchards had the lowest litter abundances and amongst the highest vigor indices for living trees.

3.1.4. Variability of the hedgerow structure

The first two dimensions of the Multiple Factor Analysis (MFA) explained, respectively, 42.13% and 24.06% of the total variability of the hedgerow structure (*figure 1D*). The first dimension opposed hedgerows whose number of tree and shrub species along the orchard perimeter and ground covering were high to those for which they were not. The number of species was correlated positively with the hedgerow composition of productive species (Use_4). The second dimension expressed the hedgerow variability that arose from their species composition, opposing boundary-marking (Use_1) and defensive (Use_2) species. About 48.1% of the orchards were surrounded entirely by a hedgerow, whereas 11.1% of them had no hedgerow at all. Orchards without hedgerows were often enclosed by walls or wire fences (data not shown). Boundary-marking and defensive species were those that mostly contributed to the hedgerow ground covering (*i.e.*, respectively 39.3% and 38.0% on average) unlike the productive and fruit species (*i.e.*, less than 5% on average).

3.2. Typology of Senegalese mango-based cropping systems based on orchard design and management patterns

The hierarchical clustering performed using the orchard design and management variables as active ones suggested a clustering into four 'orchard' clusters (*Appendix B*, *figure B1* in article online at www.fruits-journal.org). After the consolidation step, clusters 1 to 4 contained, respectively, 5, 24, 20 and 15 orchards. The four clusters define four types of cropping systems described in the following and in *figure 2A and 2B*.

3.2.1. System 1: 'No-input mango diversified orchards'

System 1 (*i.e.*, 'orchard' cluster 1) consisted of orchards with a high composition of mango trees (86.2% on average for the orchards in cluster 1 *vs.* 64.3% for all the orchards; ns) and a low composition of citrus species (10.6% *vs.* 31.7%). Diversity in mango cultivars was high (cultivar number: 3.60 *vs.* 2.25; $P < 0.01$). Cultivar Boucodiékhal was over-represented (62.0% *vs.* 27.8%; $P < 0.05$), whereas cv. Kent was under-represented (21.8% *vs.* 58.5%; $P < 0.05$). The mean local planting density of trees was low (269 *vs.* 455 trees·ha^{-1}; ns). None of these orchards were managed or supplied with inputs (*i.e.*, no picking up of fallen fruits, no fertilization, no irrigation, no pesticide applications and no soil care) nor used for cultivation of associated food or vegetable crops.

3.2.2. System 2: 'Low-input mango orchards'

System 2 (*i.e.,* 'orchard' cluster 2) consisted of orchards with a high composition of mango trees (85.7% *vs.* 64.3% for all the orchards; $P < 0.001$) and a low composition of citrus species (grapefruit: 0.2% *vs.* 11.2%; $P < 0.001$, mandarin: 5.2% *vs.* 10.8%; $P < 0.05$). On average, cv. Boucodiékhal was over-represented (48.0% *vs.* 27.8%; $P < 0.001$) because 80% of the surveyed orchards in which Boucodiékhal was the predominant mango cultivar belonged to system 2. However, in system 2 there were as many orchards in which Kent was the predominant mango cultivar as there were orchards in which Boucodiékhal was the predominant cultivar. Within orchards, the local planting densities of trees were low on average (mean: 320 *vs.* 455 trees·ha^{-1}; $P < 0.05$) and displayed low between-tree variability (coefficient of variation: 0.38 *vs.* 0.54; $P < 0.05$). The levels of use of management practices for irrigation (0.29 *vs.* 0.95; $P <$ 1e–04), fertilization (0.86 *vs.* 1.52; $P < 0.001$), pesticide applications (0.76 *vs.* 1.29; $P < 0.001$) and picking up of fallen fruit (0.24 *vs.* 0.56; $P < 0.001$) were low. Irrigation, fertilization, pesticides and fruit sanitation were not even used in, respectively, (71, 48, 48 and 86)% of the orchards. The level of

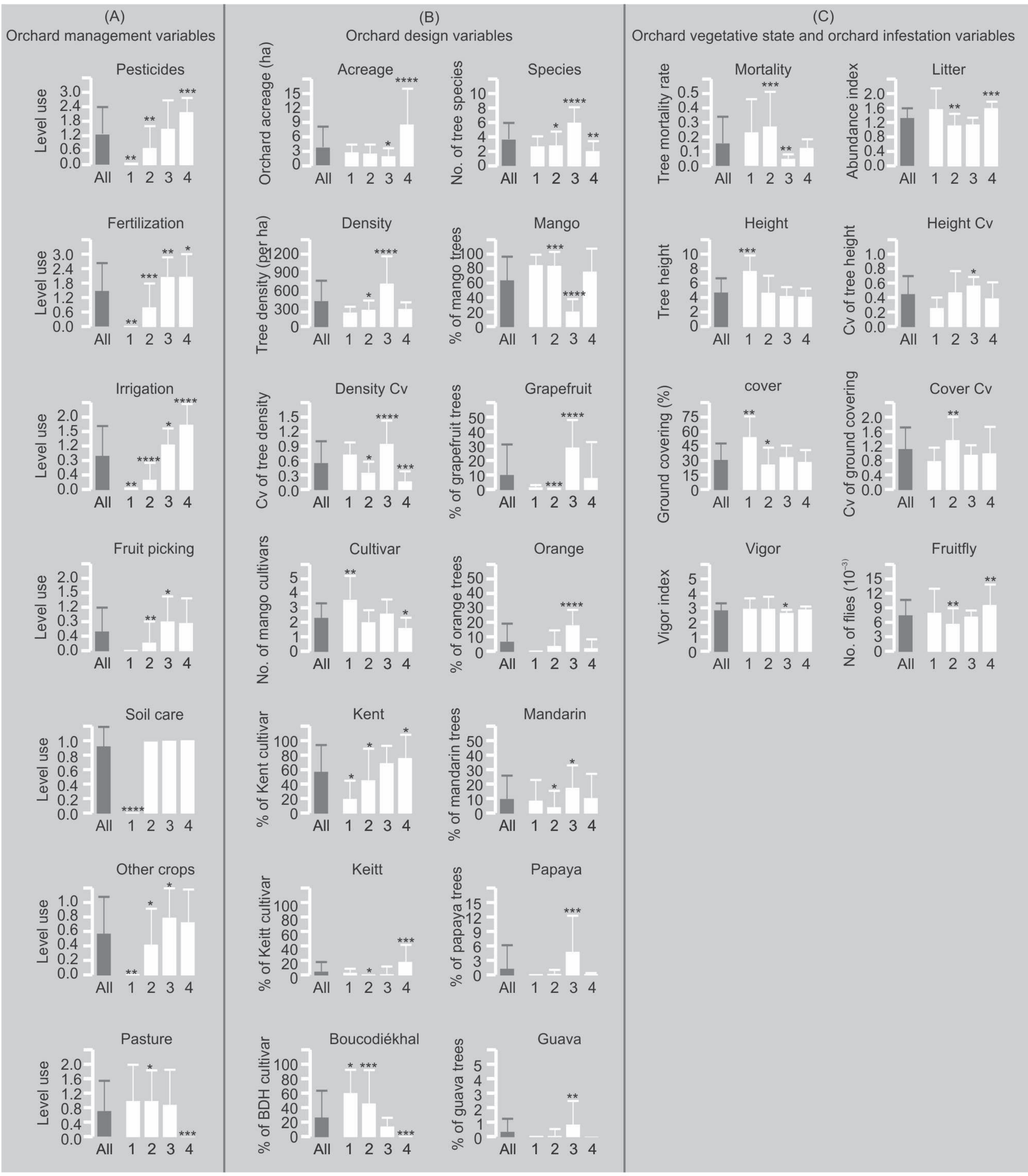

Figure 2.
Means and standard deviations of the (A) orchard management variables, (B) orchard design variables, and (C) orchard vegetative state and orchard infestation variables in the entire orchard sample (All) and 'orchard' clusters (1–4). No. of 'orchard' clusters stand for 1: 'No-input mango diversified orchards', 2: 'Low-input mango orchards', 3: 'Medium-input citrus-predominant orchards', 4: 'Medium-input large mango- or citrus-predominant orchards'. Asterisks indicate the *p-value* of the *v*-test (**** $P < 1e{-}04$, *** $P < 1e{-}03$, ** $P < 1e{-}02$ and * $P < 5e{-}02$) used to identify the variables that characterize the 'orchard' clusters the best.

secondary use of orchards for cultivation of other crops was low (0.43 *vs.* 0.59; $P < 0.05$).

3.2.3. System 3: 'Medium-input citrus-predominant orchards'

System 3 (*i.e.*, 'orchard' cluster 3) consisted of orchards with a high species diversity (number of species: 6.10 *vs.* 3.67 for all the orchards; $P <$ 1e–04). These orchards had a high composition of citrus trees, including orange (17.8% *vs.* 7.9%; $P <$ 1e–04), grapefruit (29% *vs.* 11.2%; $P <$ 1e–04) and mandarin (17.8% *vs.* 10.8%; $P < 0.05$) species, whereas the composition of mango trees was rather low (24% *vs.* 64.3%; $P <$ 1e–04). They showed the highest composition of papaya (4.9% *vs.* 1.7%; $P < 0.01$) and guava (0.9% *vs.* 0.3%; $P < 0.01$). Within orchards, the local planting densities of trees were high on average (mean: 754 *vs.* 455 trees·ha^{-1}; $P <$ 1e–04) and displayed high between-tree variability (coefficient of variation: 0.96 *vs.* 0.54; $P <$ 1e–04). Acreage was low (1.90 ha *vs.* 3.70 ha; $P < 0.05$). The levels of use of management practices such as irrigation (1.25 *vs.* 0.95; $P < 0.05$), fertilization (2.15 *vs.* 1.52; $P < 0.01$) and picking up of fallen fruit (0.85 *vs.* 0.56; $P < 0.05$) were high. All orchards were irrigated and fertilized. Fruit sanitation occurred in 70% of the orchards and 75% received pesticide treatments. Most of these orchards were used for cultivation of other crops (80% *vs.* 59%; $P < 0.05$).

3.2.4. System 4: 'Medium-input large mango- or citrus-predominant orchards'

System 4 (*i.e.*, 'orchard' cluster 4) consisted of orchards with a high acreage (8.54 ha *vs.* 3.70 ha for all the orchards; $P <$ 0.1e–04) and a low diversity of species (number of species: 2.07 *vs.* 3.67; $P < 0.01$) and mango cultivars (number of cultivars: 1.67 *vs.* 2.25; $P < 0.05$). Their composition of mango trees was high on average (76.5% *vs.* 64.3%; ns) but showed high between-orchard variability: 64.3% were mango mono-specific orchards, whereas 26.6% were citrus-predominant mixed orchards. Cultivars Kent (76.8% *vs.* 58.5%; $P < 0.05$) and Keitt (18.1% *vs.* 5.4%; $P < 0.001$) were over-represented, whereas cv. Boucodiékhal was under-represented (0.2% *vs.* 27.8%; $P < 0.001$). Within orchards, the local planting densities of trees displayed very low between-tree variability (coefficient of variation: 0.19 *vs.* 0.54; $P < 0.01$). These orchards were managed with high intensity levels for irrigation (1.80 *vs.* 0.95; $P <$ 1e–04), fertilization (2.13 *vs.* 1.52; $P < 0.05$) and pesticide application (2.20 *vs.* 1.29; $P < 0.001$). All of them were treated with pesticides and 93% were irrigated and fertilized. None of these orchards were used for pasture by animals.

3.3. Characteristics of the four types of mango-based cropping systems

Descriptions of the cropping systems using the 'illustrative' variables (*cf.* 2.3.3) relating to the orchard vegetative state (*figure 2C*), hedgerow structural pattern (*table II*) and orchard infestation by fruit fly (*figure 2C*) are presented in the following.

3.3.1. Orchard vegetative state

System 1 ('No-input mango diversified orchards') was characterized by orchards with dense and homogeneous vegetation: both mean height (7.87 m on average for the orchards in cluster 1 *vs.* 4.83 m for all the orchards; $P < 0.001$) and mean local ground covering (53.1% *vs.* 30.0%; $P < 0.01$) of trees were high and the between-tree variability was low (coefficient of variation of heights: 0.29 *vs.* 0.48; ns, coefficient of variance of local ground coverings: 0.80 *vs.* 1.13; ns). Litter abundance in these orchards tended to be above average.

The orchards of system 2 ('Low-input mango orchards') were characterized by a high mortality rate of trees (0.27 *vs.* 0.16; $P < 0.001$). The mean litter abundance index (1.10 *vs.* 1.26; $P < 0.01$) and mean local ground covering (25.4% *vs.* 30%; $P < 0.05$) of the trees were below average. The vegetation was rather heterogeneous within orchards (coefficient of variation of local ground coverings: 1.40 *vs.* 1.13; $P < 0.01$). Despite the trends observed regarding the average characteristics of these orchards, this system had high between-orchard variability.

System 3 ('Medium-input citrus-predominant orchards') was characterized by

Table II.
Repartition (%) of the 54 orchards whose hedgerow was surveyed between the 'orchard' and 'hedgerow' clusters.

Orchards	Hedgerows			
	Cluster 1 (n_q = 6)	Cluster 2 (n_q = 19)	Cluster 3 (n_q = 18)	Cluster 4 (n_q = 11)
Entire sample (*n* = 54)	11.1	35.2	33.3	20.4
Cluster 1 (n_q = 3)	33.3	0	0	66.7
Cluster 2 (n_q = 16)	12.5	37.5	25	25
Cluster 3 (n_q = 20)	10	5 ***	65 ***	20
Cluster 4 (n_q = 15)	6.7	80 ****	6.7 *	6.7

• For the orchards: cluster 1: 'No-input mango diversified orchards', cluster 2: 'Low-input mango orchards', cluster 3: 'Medium-input citrus-predominant orchards', cluster 4: 'Medium-input large mango- or citrus-predominant orchards'.
• For the hedgerows: cluster 1: 'No living hedgerows', cluster 2: 'Hedgerows with defensive species', cluster 3: 'Hedgerows with boundary-marking species', cluster 4: 'Dense hedgerows with high species diversity'.
Values represent the % orchards in the entire sample or in an 'orchard' cluster that were surrounded by a hedgerow of a given 'hedgerow' cluster (*e.g.,* 12.5% of the orchards in the 'orchard' cluster 2 were surrounded by a hedgerow of the 'hedgerow' cluster 1).
n and n_q are the number of orchards in the entire sample and clusters.
Asterisks indicate the *p-value* of the *v*-test (**** P < 1e–04, *** P < 1e–03, ** P < 1e–02 and * P < 5e–02) used to identify the variables (*i.e.*, 'hedgerow' clusters) that characterize the 'orchard' clusters the best.

orchards with a very low mortality rate of trees (0.04 *vs.* 0.16; $P < 0.01$). In addition, between-tree height variability within these orchards was slightly above the average (coefficient of variation of heights: 0.57 *vs.* 0.48; $P < 0.05$) and the mean vigor index of trees was below the average (2.66 *vs.* 2.89; $P < 0.05$).

The orchards form system 4 ('Medium-input large mango- or citrus-predominant orchards') showed average vegetative characteristics except for a high mean litter abundance index of trees (1.58 *vs.* 1.26; $P < 0.001$).

3.3.2. Hedgerow structural patterns

The variability of the hedgerow structure was summed up into four structural patterns, *i.e.*, the four 'hedgerow' clusters (*figure 3*) (detailed results on the hierarchical clustering are given in *Appendix B*; *figure B3* and *table BII* in article online). The first hedgerow pattern ('No living hedgerows'; cluster 1) consisted of hedgerows without trees or shrubs. The second pattern ('Hedgerows with defensive species'; cluster 2) consisted of hedgerows with a high composition of defensive species (64.7% on average for the hedgerows in cluster 2 *vs.* 38.0% for all the hedgerows; $P <$ 1e–04) and a low composition of boundary-marking, productive and fruit species. The third pattern ('Hedgerows with boundary-marking species'; cluster 3) consisted of hedgerows with a high composition of boundary-marking species (75.3% *vs.* 39.3%; $P <$ 1e–04) and low in defensive, productive and fruit species. The perimeter of the orchards in which these hedgerows were observed were almost entirely planted with hedgerow (98.6% *vs.* 72.3%; $P <$ 1e–04). The fourth pattern ('Dense hedgerows with high species diversity'; cluster 4) consisted of hedgerows with a very high species number (11.6 *vs.* 6.2; $P <$ 1e–04) and a high ground coverage (106.4% *vs.* 71.3%; $P < 0.01$). Their composition of productive (9.2% *vs.* 2.4%; $P <$ 1e–04) and fruit (11.6% *vs.* 3.5%; $P <$ 1e–04) species was above average.

In system 1 ('No-input mango diversified orchards') two hedgerow patterns were observed: 'No living hedgerows' and 'Dense hedgerows with high species diversity' (*table II*). In system 2 orchards ('Low-input mango orchards') the four hedgerow patterns were observed in almost equal proportion. System 3 ('Medium-input citrus-predominant orchards') was characterized

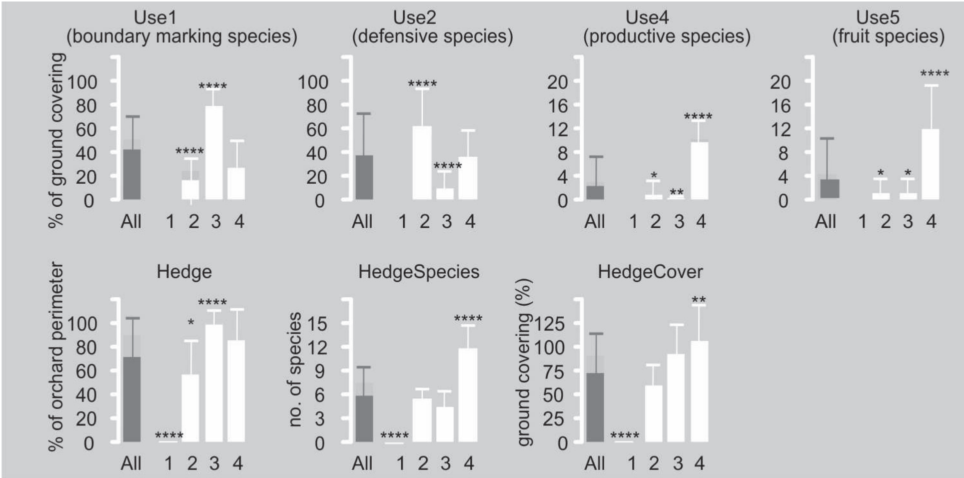

Figure 3.
Means and standard deviations of the hedgerow variables in the entire orchard sample (All) and 'hedgerow' clusters (1–4). No. of 'hedgerow' clusters stand for 1: 'No living hedgerows', 2: 'Hedgerows with defensive species', 3: 'Hedgerows with boundary-marking species', 4: 'Dense hedgerows with high species diversity'. Asterisks indicate the *p-value* of the *v*-test (**** P< 1e–04, *** P < 1e–03, ** P < 1e–02 and * P < 5e–02) used to identify the variables that characterize the 'hedgerow' clusters the best.

by the 'Hedgerows with boundary-marking species' pattern (65.0% for the orchards of system 3 *vs.* 33.3% for all the orchards; P < 0.001). System 4 ('Medium-input large mango- or citrus-predominant orchards') was characterized by the 'Hedgerows with defensive species' pattern (80.0% *vs.* 35.2%; P < 1e–04).

3.3.3. Orchard infestation by *B. invadens* fruit flies

The orchards of system 2 ('Low-input mango orchards') were characterized by a below average level of infestation by *B. invadens* fruit flies (number of trapped flies: 5890 on average for the orchards in cluster 2 *vs.* 7500 for all the orchards; P < 0.01). On the contrary, the orchards of system 4 ('Medium-input large mango- or citrus-predominant orchards') were characterized by an above average level of infestation (9720 *vs.* 7500; P < 0.01). The orchards of the two other systems showed average levels of infestation.

4. Discussion and conclusion

Our study attempted to characterize and grasp the diversity of the mango-based cropping systems existing in Senegal. Our results highlighted that the diversity of these systems arising from the orchard planting design and their yearly management for orchard maintenance could be categorized into four main patterns. An added value of the present classification, compared with previous expert-based typologies [6, 9, 10], is to characterize the types of orchards quantitatively while balancing the respective influence of design and management variables by means of a rigorous method. The detailed observation of these agronomic facts makes it possible to infer the broad strategic outlines of farmers in the four types of cropping systems. Farmers' motivation and marketing opportunities seem to dictate their technical choices, from orchard establishment to annual maintenance.

Among the orchards with mango-predominant species first, those in system 4 ('Medium-input large mango- or citrus-predominant orchards') were dedicated to the export market since they consisted of cvs. Kent and Keitt, the only two mango cultivars that are exported to Europe by Senegal [3]. But actually, inter-continental exportation of mangos could remain modest and fruits were ultimately sold wholesale on national or sub-regional markets. The little cultivar diversity could shorten the production period and facilitate timeous trade. On the contrary, orchards in systems 1 ('No-input mango diversified orchards') and 2 ('Low-input mango orchards') were mostly planted with rustic mango cultivars and were dedicated to the local market or subsistence production. Most of these rustic cultivars, such as Boucodiékhal, are poly-embryonic mangos that do not require grafting and can be simply reproduced by seeding.

Our results confirmed that mango-dominant systems dedicated to the export market contained less mango varietal diversity and displayed higher intensification levels than those dedicated to the local market, as previously suggested by Ndiaye *et al.* [10]. Although the orchards in system 4 displayed the highest intensification levels, they were rather considered as "medium-input" systems since their intensification level was the highest only in the context of the study area. For instance, the level of pesticide use can no longer be considered as "high" with regard to the 25 to 30 annual applications in apple orchards in France [35]. In system 4, orchard mechanization was facilitated by the regular row planting of trees, which is suggested by the low between-tree variability of local planting densities. In the opposite extreme, maintenance efforts to improve fruit production were not made in orchards of system 1. In addition (and despite the positive answer of farmers about the use of pruning practices), trees were presumably not pruned in these orchards since their vegetation was much more developed and dense than the vegetation of orchards in the other systems. Urbanization has been increasing in the study area for several decades, leading to an increase in land prices. In this context, the main motivation of some farmers was to sell their orchard as a building plot; and trees were mostly used for property boundary fencing. The execution of an estimated technical program is generally confronted with the availability of the factors of production and their choice of allocation to the various crops produced within the farm. In approaches aiming to design innovative cropping systems, this point underlines the interest in identifying farmers' leeway [36] and in performing cognitive approaches to farmers' cultivation practices in order to identify the drivers of practice change [37]. However, in the case of orchards in system 1 which were located in a context of strong land speculation, the driver was most certainly the evolution in farmers' motivation.

Secondly, orchards with citrus-predominant species (*i.e.*, those in system 3: 'Medium-input citrus-predominant orchards', and partly those in system 4) displayed among the highest intensification levels, although citrus fruit from Senegal is not exported but dedicated to local and national markets. Citrus cultivation requires irrigation, whereas mango does not. In Senegal the rainy season lasts only three to four months and there are no permanent rivers. Therefore, growing citrus involves considerable financial and material means when compared with mango-dominant systems to obtain water and acquire an irrigation system. From the moment the farmer irrigates it incurs costs that must be recouped, which leads him to improve cropping system management and enhance fruit marketing. Marketing mostly relies on retail sale networks. The large rank of fruit species in orchards of system 3 enables the spread of the production period and ensures market supply in fruits year-round.

The geographic localization of the sampled orchards (*Appendix B*; *table BI*) highlighted some specialization of the localities in the mode of production and marketing of mango-based orchards. Most of the orchards located around Notto were large medium-input orchards with mango for export or citrus-predominant species (system 4); and most of those located around Sébikotane were medium-input orchards with citrus-predominant species (system 3). Around the Pout and Pékou localities, there were mostly no-(or low-) input mango orchards (systems 1 and 2).

A new and interesting aspect of the present characterization of mango-based cropping systems is the description of the hedgerows around the orchards, and their classification into structural patterns relating to the uses of tree and shrub species [29]. Relation of hedgerow patterns and those of the orchard design and management were therefore included. Particularly, defensive and boundary-marking tree species were more frequent in the hedgerows around 'medium-input' orchards with either mango dedicated for export markets or citrus-predominant species (systems 3 and 4). These results can suggest that these choices target cropping systems of high added value that require protection from wind, robbers or animals. It, however, calls for an economic approach to confirm that 'medium-input' orchards are of higher added value when compared with the no- (or low-) input orchards.

Our results also supported the hypothesis that system functioning was related to farmers' technical choices. *Bactrocera invadens* flies occurred at the highest numbers in the most intensive ('medium-input) orchards with export mangos or citrus-predominant species (system 4), whereas they occurred at the lowest numbers in less intensive ('low-input') mango orchards (system 2). These results were in contrast to those of Ndiaye *et al*. [10], which were obtained in the same study area. The authors claimed that "traditional" orchards were more infested than the "modern" (intensive) ones. However, a deeper analysis of their results showed that the number of *B. invadens* flies was first higher in the traditional-type orchards but, starting from July-August, it became higher in the modern-type orchards. This second period matched with the beginning of citrus fruit production, whereas mango production occurred during both periods [10]. The availability and ripening times of host fruits claimed as important factor were influencing the fruit fly population dynamics [38]. In 2010 the mango production was low (J-Y. Rey, pers. commun.), which should have reduced fly abundance, particularly in mango-predominant orchards. Environmental conditions (*e.g.*, shading, light intensity, ambient temperatures and relative humidity) could also have influenced *B. invadens* abundance [25]. In particular, humidity might be favored by high irrigation levels in system 4, whereas low and irregular vegetation cover and low irrigation levels in system 2 were likely to decrease humidity and shading in orchards. But unexpectedly, the number of flies was the highest in orchards with the highest relative frequency of both pesticide treatments and fruit sanitation (system 4). Finally, it seems difficult to explain the differences in fruit fly abundance that were observed among the four cropping systems based on the present characterization. However, data on practice intensity do not indicate if farmers have a good mastery of the techniques they applied. For instance, if pesticides were not well applied, they could be ineffective against pests while reducing the abundance of beneficial insects. In the same way, it is possible that some farmers using fruit sanitation only gathered the fruits in the corner of the orchard without sealing them in plastic bags, which makes the practice ineffective. As practices were rarely recorded by farmers, data obtained from their declarations did not make it possible to assess the quality of application of the practices. In addition, gaps between farmers' answers and observed facts in orchards are customary in survey analyses, as previously presumed for pruning.

Our study fills an important knowledge gap in the characterization of the Senegalese mango-based cropping systems. Improved knowledge of these systems will facilitate further studies aiming to design new ones that meet stakeholders' expectations better. As a first recommendation, farmers' technical mastery of management practices should be controlled and improved by setting up technical training, for example. However, more in-depth studies on the dynamics of fruit flies are needed to understand better the roles of host fruits in and around the orchards, environmental conditions and management practices in these dynamics. Within the framework of the survey carried out in our study, it was not possible to obtain data on fruit yields from farmers. This data would have been useful to correlate host fruit availability with fly abundance. In addition, the lack of yield data also impairs the characterization of agronomic performance of the mango-based cropping systems. Further studies have been launched (i) to establish in-field measurement methods to estimate yields, and (ii) to understand better the socio-economic factors involved in the farmers' technical choices and identify the possible action levers in the cropping systems.

Acknowledgments

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References

[1] Rey J.-Y., Diallo T.M., Vannière H., Didier C., Keita S., Sangaré M., The mango in French-speaking West Africa, Fruits 61 (2006) 281–289.

[2] Rey J.-Y., Dia M.L., Mangues : des vergers villageois aux nouvelles plantations d'exportation, in : Durteurtre G., Faye M.D., Dieye P.N. (Eds.), L'agriculture sénégalaise à l'épreuve des marchés, ISRA-Karthala, Dakar, Sénégal, 2010, 257–279.

[3] Gerbaud P., Bilan de campagne 2010 par origine, FruiTrop 186 (2011) 27–39.

[4] Vayssières J.-F., Georgen G., Lokossou O., Dossa P., Akponon C.A., A new *Bactrocera* species in Benin among mango fruit fly (Diptera: Tephritidae) species, Fruits 60 (2005) 371–377.

[5] Ouédraogo S.N., Vayssières J.-F., Dabiré A.R., Rouland-Lefebvre C., Biodiversité des mouches des fruits de l'ouest du Burkina Faso : structure et comparaison des communautés de différents sites, Fruits 66 (2011) 393–404.

[6] Vayssières J.-F., Vannière H., Gueye P.S., Barry O., Hanne A.M., Korie S., Niassy A., Ndiaye M., Delhove G., Preliminary inventory of fruit flies species (Diptera: Tephritidae) in mango orchard in the Niayes region, Senegal, in 2004, Fruits 66 (2011) 91–107.

[7] Senghor A.L., Sharma K., Kumar P.L., Bandyopadhyay R., First report of mango malformation disease caused by *Fusarium tupiense* in Senegal, Plant Dis. 96 (2012) 1582.

[8] Vannière H., Didier C., Rey J.-Y., Diallo T.M., Keita S., Sangaré M., The mango in French-speaking West Africa: cropping systems and agronomical practices, Fruits 62 (2007) 187–201.

[9] Vayssières J.-F., Korie S., Coulibaly O., Temple L., Bouyei S.P., The mango tree in central and northern Benin: cultivar inventory, yield assessment, infested stages and loss due to fruit flies (Diptera: Tephritidae), Fruits 63 (2008) 335–348.

[10] Ndiaye O., Vayssières J.-F., Rey J.-Y., Ndiaye S., Diedhiou P.M., Ba C.T., Diatta P., Seasonality and range of fruit fly (Diptera: Tephritidae) host plants in orchards in Niayes and the Thiès Plateau (Senegal), Fruits 67 (2012) 311–331.

[11] Spreer W., Ongsprasert O., Hegele M., Wünsche J.N., Müller J., Yield and fruit development in mango (*Mangifera indica* L. cv. Chok Anan) under different irrigation regimes, Agric. Water Manag. 96 (2009) 574–584.

[12] Pavel E.W., de Villiers A.J., Responses of mango trees to reduced irrigation regimes, Acta Hortic. 646 (2004) 63–68.

[13] Yeshitela T., Robbertse P.J., Stassen P.J.C., Grimbeek J., van der Linde M., Fruits thinning intensities and their impact on the yield and quality of 'Sensation' (*Mangifera indica*) fruits, Trop. Agric. 80 (2003) 123–127.

[14] Vayssières J.-F., Sinzogan A., Korie S., Ouagoussounon I., Thomas-Odjo A. Effectiveness of Spinosad Bait Sprays (GF-120) in controlling mango-infesting fruit flies (Diptera: Tephritidae) in Benin, J. Econ. Entomol. 102 (2009) 515–521.

[15] Kaul V., Shankar U., Khushu M.K., Bio-intensive integrated pest management in fruit crop ecosystem, in: Peshin R., Dhawan A.K. (Eds.), Integrated pest management: innovation-development process, Springer, Netherlands, 2009.

[16] Mwatawala M.W., De Meyer M., Makundi R.H., Maerere A.P., Design of an ecologically-based IPM program for fruit flies (Diptera: Tephritidae), Fruits 64 (2008) 83–90.

[17] Nesme T., Lescourret F., Bellon S., Plénet D., Habib R., Relevance of orchard design issuing from growers' planting choices to study fruit tree cropping systems, Agronomie 23 (2003) 651–660.

[18] Blazy J.M., Ozier-Lafontaine H., Dore T., Thomas A., Wery J., A methodological framework that accounts for farm diversity in the prototyping of crop management systems. Application to banana-based systems in Guadeloupe, Agric. Syst. 101 (2009) 30–41.

[19] Deheuvels O., Avelino J., Somarriba E., Malezieux E., Vegetation structure and productivity in cocoa-based agroforestry systems in Talamanca, Costa Rica, Agric. Ecosyst. Environ. 149 (2012) 181–188.

[20] Le Bellec F., Cattan P., Bonin M., Rajaud A., Building a typology of cropping practices from comparison with a technical reference: first step for a relevant cropping system redesigning process – results for tropical citrus production, Fruits 66 (2011) 143–159.

[21] Baudry J., Bunce R.G.H., Burel F., Hedgerows: an international perspective on their origin, function and management, J. Environ. Manag. 60 (2000) 7–22.

[22] Simon S., Bouvier J.-C., Debras J.-F., Sauphanor B., Biodiversity and pest management in orchard systems. A review, Agron. Sustain. Dev. 30 (2010) 139–152.

[23] Debras J.-F., Senoussi R., Rieux R., Buisson E., Dutoit T., Spatial distribution of an arthropod community in a pear orchard (southern France): identification of a hedge effect, Agric. Ecosyst. Environ. 127 (2008) 166–176.

[24] Ricci B., Franck P., Bouvier J.-C., Casado D., Lavigne C., Effects of hedgerow characteristics on intra-orchard distribution of larval codling moth, Agric. Ecosyst. Environ. 140 (2011) 395–400.

[25] Aluja M., Birke A., Habitat use by adults of *Anastrepha obliqua* (Diptera: Tephritidae) in a mixed mango and tropical plum orchard, Ann. Entomol. Soc. Am. 86 (1993) 799–812.

[26] Yee W.L, Philips P.A., Rodgers J.L., Faber B.A., Phenology of arthropod pests and associated natural predators on avocado leaves, fruit and in leaf litter in Southern California, Environ. Entomol. 30 (2001) 892–898.

[27] Longcore T., Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, U.S.A.), Restor. Ecol. 11 (2003) 397–400.

[28] Midega C.A.O., Khan Z.R., van den Berg J., Ogol C.K.P.O., Dippenaar-Schoeman A.S., Pickett J.A., Wadhams L.J., Response of ground-dwelling arthropods to a 'push-pull' habitat management system: spiders as an indicator group, J. Appl. Entomol. 132 (2008) 248–254.

[29] Arbonnier M., Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest (2e éd.), Quae, France, 2002.

[30] Yossi H., Kaya B., Traoré C.O., Niang A., Butare I., Levasseur V., Sanogo D., Les haies vives au Sahel. État des connaissances et recommandations pour la recherche et le développement, ICRAF Occas. Paper, World Agrofor. Cent., Nairobi, Kenya, 6, 2006.

[31] Bouzillé J.-B., Gestion des habitats naturels et biodiversité. Concepts, méthodes et démarches, TEC & DOC Lavoisier, Paris, France, 2007.

[32] Lê S., Josse J., Husson F., FactoMineR: An R package for multivariate analysis, J. Stat. Softw. 25 (2008) 1–18.

[33] Husson F., Lê S. Pagès J., Exploratory multivariate analysis by example using R, Chapman & Hall/CRC, London, U.K., 2011

[34] Anon., R: A language and environment for statistical computing, R Dev. Core Team, R Found. Stat. Comput., Vienna, Austria., 2010.

[35] Aubertot J.N., Barbier J.M., Carpentier A., Gril J.J., Guichard L., Lucas P., Savary S., Savini I., Voltz M. (Eds.), Pesticides, agriculture et environnement. Réduire l'utilisation des pesticides et en limiter les impacts environnementaux, Expert. Sci. Collect. INRA – Cemagref, France, 2005.

[36] Papy F., Interdépendance des systèmes de culture dans l'exploitation, in : Malézieux E., Trébuil G., Jaeger M. (Eds.), Modélisation des agroécosystèmes et aide à la décision, CIRAD/INRA, Montpellier, France, 2001.

[37] Cerf M., Approche cognitive de pratiques agricoles : intérêts et limites pour les agronomes, Nat. Sci. Soc. 4 (1996) 327–339.

[38] Allwood A.J., Biology and ecology: prerequisites for understanding and managing fruit flies (Diptera: Tephritidae), in: Allwood A.J., Drew R.A.I. (Eds.), Management of fruit flies in the Pacific, A regional symposium, Nadi, Fiji, 1996.

Cultivos a base de mangos en Senegal: diversidad de los modelos de concepción y gestión.

Resumen – **Introducción**. Los cultivos a base de mangos en Senegal presentan una amplia variedad de sistemas. Sin embargo, existen pocas tipologías de dichos sistemas y ninguna de ellas está asociada a su análisis exhaustivo y cuantitativo. En el presente estudio, hemos definido y caracterizado la tipología de dichos sistemas basándonos en una evaluación cuantitativa de su concepción, su gestión, su estado vegetativo, la estructura de sus setos circundantes, y su infesta por una importante plaga del mango: la mosca *Bactrocera invadens*. **Material y métodos**. Se aplicaron métodos de clasificación y de análisis de variación múltiple a los datos obtenidos a partir de 64 cultivos a base de mangos y de sus setos circundantes, con muestras tomadas en las regiones de Dakar y de Thiès, en Senegal. **Resultados y discusión**. Se identificaron cuatro tipos de sistemas de cultivo según los modelos de concepción y gestión: (1) « Cultivos de mangos diversificados sin insumos », (2) « Cultivos de mangos con bajos insumos », (3) « Cultivos con *Citrus* predominantes con un nivel intermedio de insumos » y (4) « Grandes cultivos de mangos o de *Citrus* predominantes con un nivel intermedio de insumos ». Las características de los cultivos variaban según estos tipos de sistemas. Por ejemplo, la vegetación era densa y homogénea en el sistema 1. El índice de mortalidad de los árboles era elevado en el sistema 2 pero reducido en el sistema 3. Los cultivos de los sistemas 3 y 4 se asociaban principalmente a setos con especies de demarcación y especies defensivas, respectivamente. Por último, la cantidad de moscas *B. invadens* era elevada en los cultivos del sistema 4, pero reducida en los del sistema 2. **Conclusión**. Ya queda debidamente descrita y cuantificada la diversidad de los sistemas de cultivo a base de mangos en Senegal. Dicha caracterización constituye una fase preliminar indispensable para proseguir los estudios encaminados a mejorar dichos sistemas.

Senegal / *Mangifera indica* / árboles frutales / huerto frutal / tipología / diseño / manejo del cultivo / *Bactrocera invadens* / cerca viva / análisis multivariante