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Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: An attempt towards a regional typology

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ABSTRACT

Developing appropriate and innovative technologies and policies to respond to the challenges that urban and peri-urban agriculture (UPA) faces in West Africa requires a better understanding of the existing production systems. Although there is an increasing recognition of the importance of UPA in the region, its extent, forms and related practices may vary across countries and cities because of different socio-economic conditions and urbanization patterns. A systematic classification of the regional UPA systems is lacking but is necessary to allow for meaningful comparisons between cities and avoid misleading generalizations. The purpose of this study was to develop a typology of UPA households across three selected West African cities. Survey data from 318 UPA households (Kano: 99, Bobo Dioulasso: 111, Sikasso: 108) were submitted to principal components analysis for categorical variables (CATPCA). Next, the Two-Step cluster method was used to classify the households using object scores obtained from the CATPCA. Diversification of farm activities, farm resource endowment and production orientation were the major discriminating variables. In each city, four distinct UPA systems were identified, of which three were common to Kano, Bobo Dioulasso and Sikasso: commercial gardening plus field crops and livestock (59%, 18%, and 37%), commercial livestock plus subsistence field cropping (14%, 41%, and 7%), and commercial gardening plus semi-commercial field cropping (14%, 28%, and 30%). The fourth group was different at each location and was characterized as follows: commercial gardening plus semi-commercial livestock in Kano (13%), commercial field cropping in Bobo Dioulasso (13%) and commercial gardening in Sikasso (26%).

1. Introduction

1.1. Importance of urban and peri-urban agriculture in West Africa

Urban and peri-urban agriculture (UPA), which can be defined as the cultivation of crops and rearing of animals for food and other uses within and around cities (Mougeot, 2000) is not a new phenomenon in West Africa (Kironde, 1992; Rakodi, 1988) and has continued to rise as a consequence of rapid urbanization associated with high levels of under- and unemployment and increasing food demand of urban dwellers (Drechsel & Dongus, 2010). There is a wealth of literature that describes the social roles of UPA, its economic functions and its potentials to sustain the livelihoods of urban dwellers in West African countries, along with its environmental benefits (Asomani-Boateng, 2002; Cissé, Gueye, & Sy, 2005; Danso, Drechsel, Wiafe-Antwi, & Gyiele, 2002; De Bon, Parrot, & Moustier, 2010; Graefe, Schlecht, & Buerkert, 2008; Smit, Ratta, & Nasr, 1996). On the other hand, a number of UPA practices raised concerns about associated negative side-effects on human health and environmental quality. The potential risks ensuing directly or indirectly from UPA are linked to inappropriate use of agrochemicals in plant and animal production, over-application of mineral fertilizers, use of untreated livestock and human excreta as well as household wastes as manure, use of untreated wastewater for irrigation of vegetables, and inappropriate or inadequate food handling, processing and storage (Amoah, Drechsel, Abaidoo, & Ntow, 2006; Binns, Maconachie, & Tanko, 2003; Brock & Foeken, 2006). Within the large number of available scientific and 'grey' publications on UPA crop and animal production in West Africa, each study presents a particular set of data for a well-defined production context and for specifically defined research questions. These cover practically all aspects of UPA, such as appropriate dosing of mineral fertilizers (Drechsel & Zimmermann, 2005), targeted

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application of organic manure to vegetable gardens (Drechsel, Abaidoo, Amoah, & Cofie, 2000), improved urban milk production (Millogo, Ouedraogo, Agenäs, & Svennersten-Sjaunja, 2008; Sidibe, Boly, Lakouetene, Leroy, & Bosma, 2004) and the externalities linked to wastewater reuse in vegetable cultivation (Eaton & Hilhorst, 2003; Niang, Diop, Faruqui, Redwood, & Gaye, 2002; Sonou, 2001). However, these individual case studies often ignored the interdependencies of bio-physical and socio-economic conditions at the scale of a farm and a town, and the interrelatedness of plant and animal production as well as the interrelatedness of resource use efficiencies and externalities in production processes. Because these case studies lack a proper typology and systems research approach, only very limited broader conclusions and policy recommendations can be drawn from their findings. There is thus a need to scale up the findings from case studies (Pearson, Pearson, & Pearson, 2010) while taking into account the specific socio-economic, environmental and institutional context within which urban agriculture is taking place in each country (Bryld, 2003).

1.2. Classification of urban and peri-urban farming systems in West Africa

Several studies have used various criteria to describe local urban farming systems in different West African countries. Often, these criteria varied according to authors' discipline and the purpose of the classification, and some authors used only one criterion. For example, Schilter (1991) used time allocation to classify urban farmers in Lomé, Togo, and distinguished between full-time, part-time and temporary urban farmers. Based on the location where the activity is carried out, three major UPA systems were identified in Accra, Ghana (Asomani-Boateng, 2002) and in the metropolis of Katsina, Northern Nigeria (Ruma & Sheikh, 2010). These were: peri-urban, vacant/open space and household farming systems. Other studies used a combination of criteria to differentiate among urban farming systems. Kessler (2003) used the type of crop grown and the cultivation practices to describe different farming systems in Lomé (Togo), Cotonou (Benin), Bamako (Mali) and Ouagadougou (Burkina-Faso). Danso et al. (2002) used similar criteria to distinguish four crop production systems in Accra, Ghana. Drechsel, Graefe, Sonou, and Cofie (2006), using production systems and product destination next to location, distinguished between open space market gardening, subsistence backyard gardening and livestock husbandry and aquaculture systems. Most of the studies focused on crop and vegetable production sub-systems and lacked a systems approach. Moreover, the results of these studies are hardly comparable, since the criteria used are generally qualitative and vary greatly among authors. Research on faming systems that rely on purely qualitative methods can produce useful typologies but quantitative comparison of the results is not possible without using any appropriate quantitative classification methods (Kostrowicki, 1977).

1.3. Multivariate approaches for classification

Several statistical methods exist and have been widely used in different disciplines for classification purposes. The most frequently applied methodology is based on multivariate techniques, such as Factor Analysis (FA), Discriminant Analysis (DA), Multidimensional Scaling (MDS), Principal Component Analysis (PCA) and Cluster Analysis (CA). Like FA, DA and MDS, PCA is a method to reduce the dimensionality of data by transforming the original set of correlated variables into a smaller and more understandable set of uncorrelated variables (Jolliffe, 2002) whereas CA is used to create homogeneous groups of objects based on the characteristics of these objects as described in the data set (Everitt, Landau, & Morven, 2001; Hair, Black, Babin, Anderson, & Tatham, 2006). There are many clustering methods, and each of them may give a different grouping of a dataset (Gelbard, Goldman, & Spiegler, 2007). The two most widely used clustering methods are the hierarchical and the K-means clustering methods. In the hierarchical procedure, a tree-like structure is built to see the relationship among entities whereas in the K-means procedure a position in the measurement is taken as central place and distance is measured from such central point.

PCA and CA have been used to identify farm types worldwide (Bidogeza, Berentsen, De Graaff, & Oude Lansink, 2009; Gebauer, 1987; Joffre & Bosma, 2009; Köbrich, Rehman, & Khan, 2003; Kostov & McErlean, 2006; Maseda, Dıaz, & Alvarez, 2004; Siegmund-Schultze & Rischkowsky, 2001; Somda, Kamuanga, & Tollens, 2005). However, although commonly used, these techniques are often not the most appropriate methods in a good number of farming systems studies. For example, the appropriate use of the standard PCA, like FA, DA and MDS techniques, is based on the powerful assumptions that all variables are continuous and that the relationships between them are linear (Jolliffe, 2002). Since the complexity of farming systems requires an interdisciplinary research approach (Collinson, 2000; Zandstra, 2006), many variables used to describe local farming systems are nominal and relationships between them are frequently nonlinear. Similarly, each of the two traditional techniques of K-means and hierarchical clustering widely used in the above mentioned studies has its limitations. An important step in any of these two procedures is to select a distance measure that determines how the similarity of two objects is calculated. Unfortunately, none of the distance measures in hierarchical clustering or K-means are suitable for use with variables of mixed measurement levels (Huang, 1998).

To overcome the limitations of standard PCA, a nonlinear PCA has been developed (Gower & Blasius, 2005) and is available as Categorical Principal Component Analysis program (CATPCA) in the Categories Module of SPSS® (Linting, Meulman, Groenen, & Van der Kooij, 2007; Meulman, Heiser, & SPSS Inc., 2004). CATPCA is a multivariate technique intermediate between standard (linear) PCA and nonlinear multiple correspondence analysis (Blasius & Greenacre, 2006). In contrast to linear PCA, CATPCA can handle variables of different analysis levels (nominal, ordinal, and numerical) simultaneously, and can deal with nonlinear relationships between variables (Linting et al., 2007). It is therefore adapted for use in social and behavioural science (Meulman et al., 2004), but also in cross-disciplinary research like farming systems research where variables resulting from surveys are often non-numeric. Similarly, to overcome the major of the above-mentioned limitations of K-means and hierarchical clustering methods, a Two-Step clustering method was developed based on the Balance Iterative Reducing and Clustering using Hierarchies (BIRCH) algorithm (Zhang, Ramakrishnon, & Livny, 1997) and implemented in SPSS (Meulman et al., 2004). The Two-Step cluster procedure of SPSS possesses two very important features that distinguish it from traditional clustering techniques (Bacher, Vogler, & Wenzig, 2004). First, it permits the use of categorical variables along with continuous variables and reduces the size of the data set by generating a fairly large number of pre-clusters. Second, it can automatically determine the optimal number of clusters but also gives the opportunity to the user to pre-specify the numbers of clusters required. As prerequisites for a Two-Step cluster analysis, continuous variables must be normally distributed and categorical ones multi-nominally distributed; moreover, the variables must be independent of each other (SPSS Inc., 2001). Fortunately, the procedure is fairly robust to violations of both assumptions (Chan, 2005), making it therefore a suitable clustering technique for multi-dimensional data sets (Linting et al., 2007; Meulman et al., 2004). In a comparative study of 11 clustering methods applied on four known data sets, Gelbard et al. (2007) highlighted the superiority of the Two-Step Clustering method over the Hierarchical and K-means algorithms. Yet, the Two-Step cluster algorithm has also shown some limitations. Differences in categorical variables may be given a higher weight than differences in continuous variables, and the method is not able to correctly detect models with no cluster solutions (Bacher et al., 2004). Other alternative clustering approaches such as the Latent Class Models (Magidson & Vermut, 2002) and the Mixtures of Distributions Model MDM (Kostov & McErlean, 2006) have been developed to allow the inclusion of variables of mixed scale types and to overcome the shortcomings of the classical clustering methods. However, unlike for the classical and Two-Step cluster methods, tools for these alternative methods are not available in most of the established econometrical or statistical packages.

The purpose of this study was to apply multivariate analysis techniques so as to develop a common typology of urban households participating in UPA in three selected West African cities located in three different countries. If successful, such a typology can provide the basis for in-depth characterization of existing UPA systems and the identification of their (production) opportunities and challenges and the subsequent development of recommendation domains at local and regional scales.

2. Materials and methods

The dataset used in this study was derived from a baseline survey of a larger ongoing study aiming at a consistent quantitative characterization of resource use efficiencies and environmental externalities of UPA in the three secondary West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali).

With a population estimated at 3.14 million inhabitants in 2007 (UNUP, 2009), Kano in northern Nigeria is the country's second largest city after Lagos. It covers a total area of 550 km^2 (Tiffen, 2001). Bobo Dioulasso, located in the south-western part of the country, is the second largest city in Burkina-Faso after Ouagadougou. With an estimated population of 400,000 inhabitants in 2007, it covers a land area of 136.78 km^2 (Commune de Bobo Dioulasso, 2007). Located in the south-east of Mali, Sikasso is the third largest city of this country after Bamako and Segou. It covers a land area of 37.45 km^2 (Ministère de l'Habitat et de l'Urbanisme, 2005) and has an estimated population size close to 200,000 inhabitants. While Kano is located in the Sudano-Sahelian agroecological zone, Bobo Dioulasso and Sikasso are situated in the Sudanian zone of West Africa.

2.1. Data collection

A snowball sampling procedure (Babbie, 2009) was used to randomly select and interview 99 households in Kano, 111 in Bobo Dioulasso and 108 in Sikasso. The interviews were performed from March to June 2007 using a standardized semi-structured questionnaire. The variables selected for our typology are shown in Table 1 and are derived from the information recorded from heads of households or their representative. These information included the demographic and socio-economic characteristics of households, the resources owned, their involvement in different agricultural activities in and around the respective city, their production constraints, access to UPA supporting institutions and contribution of UPA activities to household income.

2.2. Statistical analyses

After data cleaning (removal of incomplete household data sets), a manual expert classification of the households was performed based on the assets (land, namely gardens and fields) and livestock managed by the households, leading to the categories garden (G), field crop (C), livestock (L), garden and field crop (GC), garden and livestock (GL), livestock and field crop (LC) and garden-field crop and livestock (GCL) households. These categories were subsumed under the variable UPATYP, which indirectly describes the level of diversification of UPA activities. The total active family work force in man-day equivalents was calculated by applying conversion factors to male and female household members in different age groups as follows: 1.0 for males aged between 16 and 55 years; 0.75 for females between 15 and 55 years; 0.75 for males above 55 years and 0.5 for females above 55 years. Household members below 15 years of age were not considered in workforce calculations.

The clustering procedures were performed separately for each city. As the dataset contained nominal and metric variables, we used the Categorical Principal Component Analysis (CATPCA) implemented in the Categories Module of SPSS/PASW 18 (SPSS Inc., 2010), to explore the relationships between the variables and to reduce the original set of 26 variables into a smaller number of components.

We first performed the CATPCA analysis with all 26 variables listed in Table 1. Regardless of city, sex and marital status of the household heads were alike. Almost all household heads were male and married. There was therefore almost no variability to capture

Table 1
Description of household socio-economic variables used in the categorical component analysis (CATPCA) on 99, 11 and 108 households (HH) in the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali), respectively.

Variables	Description
Nominal	
SEX	Gender of HH head (male, female)
M_Status	Marital status of HH head (married, unmarried, divorced/widowed)
MIGR	Migration status of HH head (immigrant, native)
EDUC	Formal education level of HH head (none, primary, secondary, university)
LIVH	Is the HH involved in (peri) urban animal husbandry? (yes, no)
GARDH	Is the HH involved in (peri) urban gardening? (yes, no)
CROPH	Is the HH involved in (peri) urban field crop cultivation? (yes, no)
INC_GAR	Contribution of gardening to total HH income (highest, moderate, low, none)
INC_FIEL	Contribution of field cropping to total HH income (highest, moderate, low, none)
INC_LIV	Contribution of animal husbandry to total HH income (highest, moderate, low, none)
INC_REGSAL	Contribution of regular salary to total HH income (highest, moderate, low, none)
INC_OCCW	Contribution of occasional work to total HH income (highest, moderate, low, none)
UPATYP	Type of UPA enterprise (G, C, L, GC, GL, LC, GCL)
Metric	
AGE	Age of HH head (in years)
HHSIZE	Total household size, defined as total numbers of permanent family members
EXP_UPA	Number of years of experience in UPA
NGAR	Number of gardens cultivated
GARSIZ	Total garden size (in m^2)
NFIELD	Number of crop fields cultivated
FIELSIZE	Total field size (in ha)
NPOULTRY	Total number of poultry reared
TLU_Total	Total number of animals reared, expressed in TLU[a]
R_LABOR	Total active family work force in man-days as a proportion of HHSIZE
R_EDUCM	Total educated HH members as a proportion of HHSIZE
R_REGSAL	Total HH members with regular salary as a proportion of HHSIZE
R_TEMPSAL	Total HH members with temporary salary as a proportion of HHSIZE

[a] TLU: tropical livestock unit, hypothetical animal of 250 kg live weight; TLU conversion factors used: camel = 1, cattle = 0.80, sheep and goats = 0.10, donkey = 0.5; pigs = 0.20, poultry and rabbit = 0.01.

Table 2
CATPCA model summary and component loadings for the three West African cities of Kano, Bobo Dioulasso and Sikasso.

	Kano (n = 99)		Bobo Dioulasso (n = 111)		Sikasso (n = 108)	
Total Cronbach's Alpha[a]	0.906		0.926		0.905	
Total Eigenvalue	7.523		8.720		7.461	
Total % variance	32.708		37.910		32.439	
	Dimension					
	1	2	1	2	1	2
Cronbach's Alpha	0.786	0.746	0.871	0.662	0.808	0.704
Total Eigenvalues	4.037	3.486	5.991	2.728	4.396	3.065
% of total variance	17.551	15.157	26.048	11.861	19.113	13.326
Label	Component loadings					
AGE	0.228	0.373	−0.030	−0.055	−0.452	0.221
MIGR	−0.143	0.045	−0.590	−0.508	0.257	−0.158
EDUC	−0.215	−0.282	−0.094	0.243	−0.227	0.186
HHSIZE	0.320	−0.044	0.074	0.003	−0.013	0.443
R_LABOR	0.132	0.297	−0.095	0.117	−0.008	−0.232
R_EDUCM	0.132	0.199	−0.135	0.228	−0.377	−0.263
R_REGSAL	0.235	0.268	−0.301	−0.122	−0.298	−0.225
R_TEMPSAL	−0.074	0.078	0.109	−0.081	−0.237	−0.396
LIVH	−0.176	0.578	0.720	−0.451	0.741	−0.158
GARDH	0.917	−0.086	−0.856	−0.408	−0.028	0.842
CROPH	0.028	0.751	0.466	−0.379	0.523	−0.368
EXP_UPA	0.288	0.540	0.067	0.477	−0.292	−0.015
NGAR	−0.839	−0.046	0.856	0.408	−0.107	−0.769
GARSIZ	−0.481	−0.087	0.657	0.341	−0.219	−0.214
NFIELD	−0.124	−0.742	−0.132	0.364	−0.724	0.186
FIELSIZE	−0.055	−0.617	−0.264	0.723	−0.618	0.073
TLU_Total	0.675	−0.510	−0.706	0.222	−0.529	0.018
NPOULTRY	−0.102	−0.247	−0.654	0.213	−0.740	0.001
INC_GAR	0.926	−0.076	−0.868	−0.337	−0.030	0.861
INC_FIEL	0.245	0.525	0.548	−0.377	0.646	0.189
INC_LIV	−0.646	0.282	0.813	−0.307	0.623	0.113
INC_REGSAL	0.068	−0.401	0.344	0.077	−0.408	−0.142
INC_OCCW	−0.067	−0.279	−0.110	0.433	−0.336	−0.273
UPATYP[b]	−0.889	0.326	0.964	0.105	0.683	−0.650

[a] Total Cronbach's Alpha is based on the total Eigenvalue.
[b] Supplementary variable.

for the variables sex and marital status which were removed from the analysis.

The CATPCA was thus performed again with the 24 remaining variables. The grouping variable (UPATYP) was fitted in the CATPCA solution by choosing a "multiple nominal" scaling level and treating the variable as supplementary. A supplementary variable has no influence on the actual analysis, but its quantifications are computed afterwards to establish its relationship with the solution obtained (Meulman et al., 2004). The rule of thumb of retaining the components that contain a minimum of four variables having a loading score >0.60 (Stevens, 1992) was applied to choose the number of reliable principal components. The higher the loading of a variable on a given principal component, the more that variable contributes to the variation accounted for by this component. Therefore, in this study, we selected only those variables that loaded greater than 0.5 on one of the retained components for further analysis; a similar cut-off level was used by Costantini, Linting, and Porzio (2010) and Dominguez-Rodrigo, de Juana, Galan, and Rodriguez (2009) for significant indicator loadings. The perceptual maps yielded in the CATPCA were used to predict a priori the number of homogeneous groups in the data sets. The extracted component scores were subsequently used as inputs in the cluster analysis. Two clustering approaches were explored: the non-hierarchical Two-Step and the classical hierarchical approach using the Ward's method. In the Two-Step cluster analysis, the higher weighting of categorical variables at the expense of the continuous variables in the clustering process may be an important issue (Bacher et al., 2004). Therefore we used the visual binning procedure to convert the selected continuous variables into nominal variables before their submission to the algorithm. Furthermore, since the Two-Step clustering result is influenced by the order in the records of the data set (Bacher et al., 2004), we ran the analysis four times for each country with random orders of variables.

The number of clusters to fix was determined on the basis of the Bayesian Information Criterion (BIC). Several cluster solutions were then explored and the overall silhouette measure of cluster cohesion and separation (Jain & Koronios, 2008; Rousseeuw, 1987) was used to evaluate the goodness of the cluster solution. A silhouette is a graphical aid to the interpretation and validation of cluster analysis that provides a measure of how well a subject is classified when it is assigned a cluster membership. A cluster cohesion and separation value >0.7 indicates an excellent separation between the clusters, a value between 0.5 and 0.7 indicates a clear assignment of data points to cluster centers, values between 0.25 and 0.5 indicate that there are many data points that cannot be clearly assigned and values <0.25 indicate that it is practically impossible to find significant cluster (Kaufman & Rousseeuw, 1990). For the sake of comparison, the same variables used in the Two-Step cluster algorithm were also submitted to hierarchical cluster analysis using the Ward's method and the squared Euclidean distance, and the resulting Elbow diagram was used to derive the number of clusters.

The final clusters obtained were profiled and a cluster name was assigned to each. Cross tabulations were used to show the distribution of each UPA activity and its households' income contribution across clusters. Differences between clusters in households'

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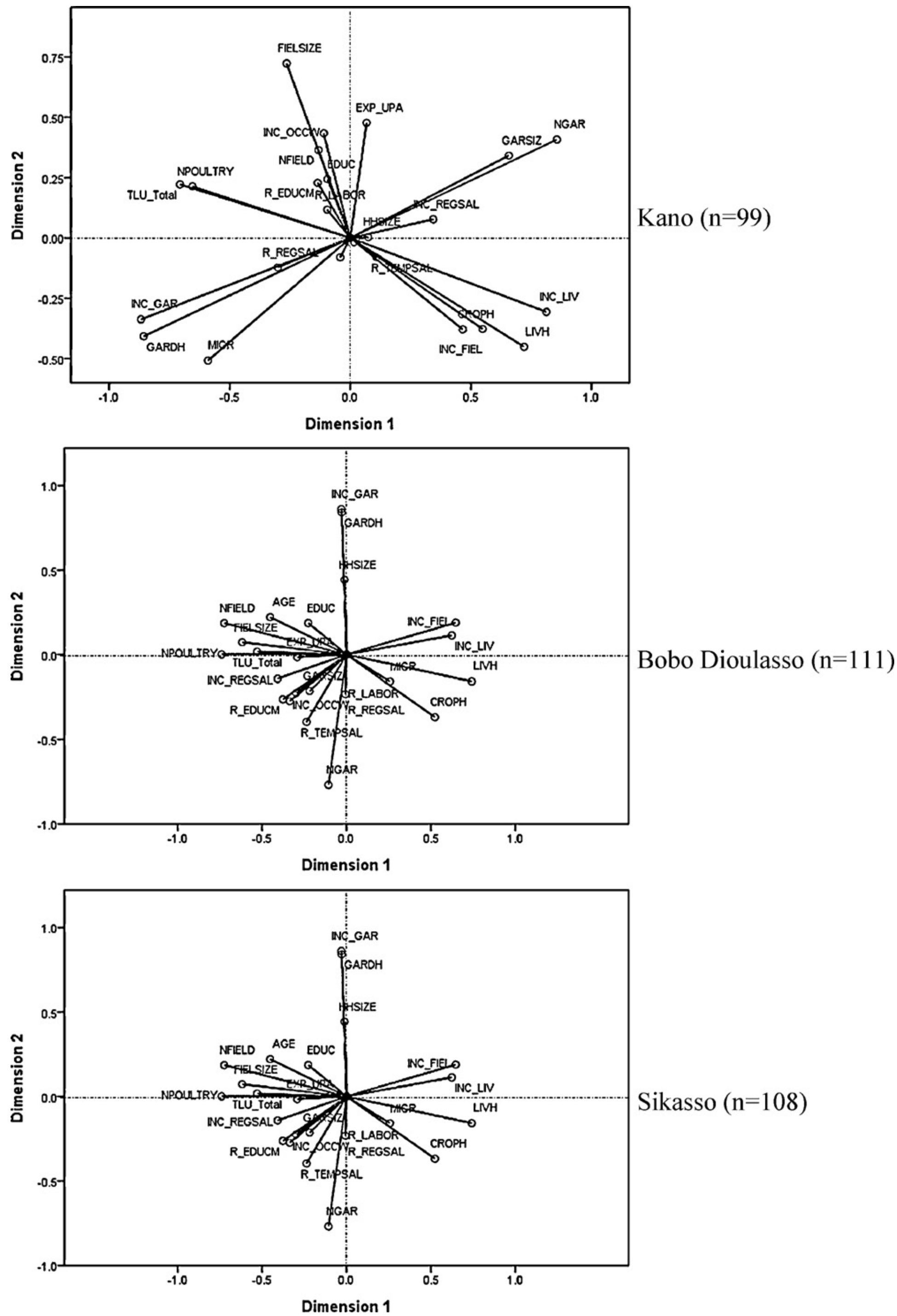

Fig. 1. Plots of component loadings obtained from CATPCA for Kano, Bobo Dioulasso and Sikasso describing the relationships among household socio-economic characteristics.

resources endowments were explored using the Kruskal–Wallis test. Next, an internal cross-validation of the identified groups was performed using multinomial regression analysis. Finally, a cross-tabulation of the final clusters with the supplementary variable representing the expert's manual classification (UPATYP) was used as a validity check.

3. Results

The variables related to UPA activities were distributed into two components by CATPCA (Table 2). The introduction of a third component increased the total variance accounted for by approximately 10% in each city; however, only two variables related to household socio-economic characteristics were placed into this additional dimension: R_EDUCM and R_REGSAL in Kano; INC_OCCW and R_REGSAL in Bobo Dioulasso; R_TEMPSAL and INC_OCCW in Sikasso. Therefore, we decided to continue the exploration of data with the two-component solution. Variables that scored more than 0.5 in at least one of the two components were used in the classification of households. Fig. 1 shows the two-dimensional component loading plots obtained with CATPCA, summarizing the relationships between the different variables. These relationships, represented by their correlations with the principal components, are displayed by vectors pointing towards the category with the highest score.

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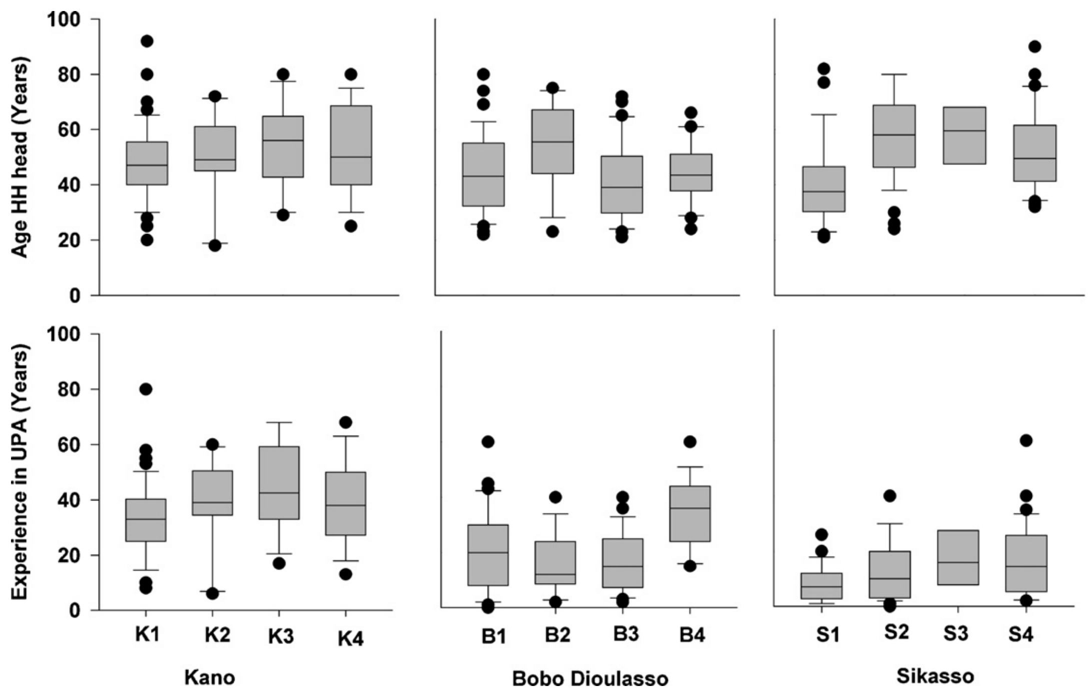

Fig. 2. Mean values for the age of head of households and households' experience in UPA across the final four clusters in Kano, Bobo Dioulasso and Sikasso.

Regardless of the city, the most influential variables as reflected by the length of the vectors were identified as those related to diversification of UPA activities (GARDH, LIVH and CROPH), to income contribution of different UPA activities (INC_GAR, INC_LIV and INC_FIEL) and to resource endowment (NGAR, NFIELD, FIELSIZE, TLU_Total).

Fig. 1 suggests that a priori four groups of households can be identified in each city, as a result of the relationships among the most influential variables. The automatic clustering procedure of the Two-Step cluster algorithm suggested a four-cluster solution for each city. The quality of the clustering solution was good with an overall silhouette measure of 0.6 for each city. However, given the fact that the supplementary variable (UPATYP) used in the CATPCA had seven levels of measurements reflecting the different combinations possible of UPA activities, a number of possible cluster solutions, ranging from three to seven, were considered.

The three- and five-cluster solutions were both plausible but the overall silhouette measure of cluster cohesion and separation was lower than 0.6, indicating poorer cluster quality. Therefore, a final four-cluster solution that confirmed the four a priori groups suggested by the CATPCA was adopted for all cities. The distribution of the final clusters is shown in Table 3.

In the hierarchical clustering analysis, using the same influential variables obtained from the CATPCA, the curve of the Elbow diagram inflected at a 13–15 cluster-solution for Kano, a 11–13 cluster-solution for Bobo Dioulasso and a 16–18 cluster-solution for Sikasso. These solutions resulted in very small numbers of households per groups, which were very difficult to characterize unanimously.

In the Two-Step cluster analysis, a variable cluster member was created that identified which household belong to which cluster. A profiling of the clusters was performed by crossing the variable cluster membership with both qualitative (Table 4) and quantitative (Table 5 and Fig. 2) variables that were used in the clustering algorithm. A closer look at the clusters across countries revealed strong similarities between cluster 1 of Kano, cluster 4 of Bobo Dioulasso and cluster 2 of Sikasso. Likewise, cluster 3 of Kano was similar to cluster 3 of Bobo Dioulasso and cluster 4 of Sikasso whereas cluster 4 of Kano was similar to cluster 1 of Bobo Dioulasso and cluster 3 of Sikasso. Consequently, cluster names for six different UPA production systems were specified (Table 6). These final groups had correct classification rates of 100% overall, whereas overall correct classification of the initial pre-defined groups (UPATYP) in the final groups was 98% in Kano and Sikasso and 100% in Bobo Dioulasso (Table 7).

Table 3
Distribution of households across the final clusters derived from the Two-Step cluster analysis for the three West African cities of Kano, Bobo Dioulasso and Sikasso.

	Percentage of households		
	Kano (n = 99)	Bobo Dioulasso (n = 111)	Sikasso (n = 108)
Cluster 1	58.6	41.4	25.9
Cluster 2	14.1	12.6	37.0
Cluster 3	14.1	27.9	7.4
Cluster 4	13.1	18.1	29.6
Total	100.0	100.0	100.0

4. Discussion

4.1. Methodology

The decision to apply multivariate methods or to simply stratify using a single criterion (e.g. location) is determined by the quality of the available data set (Selter, Hartebrodt, Brandl, & Herbohn, 2009). Likewise, the quality of a typology depends on the choice of the appropriate clustering method and on the quality of the data (Emtage, Harrison, & Herbohn, 2006; Gelbard et al., 2007). The two crucial issues in using classical cluster analysis techniques are the selection of the variables to be submitted to the cluster algorithm and deciding the most suitable number of clusters. In our study, the use of the CATPCA as data reduction technique permitted to integrate variables of different measurement levels in the analysis and provided an a priori idea about the number of groups. The four groups of UPA farmers for each city suggested by the CATPCA were then confirmed by the Two-Step cluster anal-

Table 4
Frequency distribution of gardening, animal husbandry and field crop cultivation activities and their relative contribution to households' income across the final four clusters in the West African cities of Kano, Bobo Dioulasso and Sikasso.

	Clusters Kano				Clusters Bobo Dioulasso				Clusters Sikasso			
	K1 (n = 58)	K2 (n = 13)	K3 (n = 14)	K4 (n = 14)	B1 (n = 46)	B2 (n = 14)	B3 (n = 31)	B4 (n = 20)	S1 (n = 28)	S2 (n = 40)	S3 (n = 8)	S4 (n = 32)
Percentage of households												
Gardening												
Yes	100	69	100	0	0	0	100	100	100	100	0	100
No	0	31	0	100	100	100	0	0	0	0	100	0
Animal husbandry												
Yes	100	100	0	93	100	0	0	100	0	100	63	0
No	0	0	100	7	0	100	100	0	100	0	37	100
Field crop cultivation												
Yes	100	0	43	79	96	100	65	100	0	83	100	100
No	0	100	57	21	4	0	35	0	100	17	0	0
Income gardening												
Highest	91	61	93	0	0	0	84	50	75	65	0	75
Moderate	7	8	7	0	0	0	16	40	25	28	0	19
Low	2	0	0	0	0	0	0	0	0	7	0	6
None	0	31	0	100	100	100	0	10	0	0	0	0
Income livestock												
Highest	7	15	0	72	52	0	0	20	0	0	12	0
Moderate	29	39	0	14	39	0	0	20	0	13	13	0
Low	16	0	0	0	7	0	0	25	0	30	0	0
None	48	46	100	14	2	100	100	35	100	57	75	100
Income crop cultivation												
Highest	0	0	0	14	48	71	13	35	0	25	0	25
Moderate	41	0	7	22	42	29	49	40	0	35	13	34
Low	14	0	0	0	8	0	0	25	0	10	0	3
None	45	100	93	64	2	0	38	0	100	30	87	38

Table 5
Mean values for households' resource endowment variables across the final four clusters in the West African cities of Kano, Bobo Dioulasso and Sikasso.

	Clusters Kano				Clusters Bobo Dioulasso				Clusters Sikasso			
	K1	K2	K3	K4	B1	B2	B3	B4	S1	S2	S3	S4
Resource endowment profile												
Total garden size (m^2)												
n	58	9	14	14	46	14	31	20	28	40	8	32
Mean	1236^{a}	1004^{a}	841^{a}	0	0	0	737^{a}	797^{a}	2257^{a}	4145^{a}	0	2647^{a}
SD	1160	791	843	0	0	0	598	744	2716	4985	0	2810
Total crop field size (ha)												
n	58	13	6	14	44	14	20	20	28	38	8	32
Mean	1.3^{a}	0.0	0.8^{a}	1.1^{a}	3.3^{ad}	1.8^{bc}	2.4^{ac}	4.6^{d}	0.0	2.8^{a}	1.7^{a}	2.0^{a}
SD	1.2	0.0	0.4	0.5	2.3	1.2	1.6	3.1	0.0	3.1	1.5	2.5
Total TLU (n)												
n	58	13	14	13	46	14	31	20	28	40	5	32
Mean	2.3^{a}	2.5^{a}	0.0	40.1^{b}	21.4^{a}	0.0	0.0	4.4^{b}	0.0	7.5^{a}	21.5^{a}	0.0
SD	3.5	3.8	0.0	35.5	30.5	0.0	0.0	8.8	0.0	10.8	42.3	0.0
Total active family work force in man-equivalent (n)												
n	58	13	14	14	46	14	31	20	28	40	8	32
Mean	4.5^{a}	4.4^{a}	5.9^{a}	8.8^{a}	3.6^{a}	3.9^{a}	3.9^{a}	3.5^{a}	5.8^{a}	10.6^{a}	8.9^{a}	6.6
SD	3.9	1.6	3.9	7.5	2.5	2.6	2.3	1.7	4.4	10.1	8.3	4.6

abcd Means with different superscripts differ significantly (Kruskal–Wallis test, $P \leq 0.05$).

ysis, while the hierarchical clustering approach using the Ward's method and the squared Euclidean distance suggested for each city at least 10 groups of small sizes and of low interpretability. Different and varied cluster solutions were also reported by Gelbard et al. (2007) when applying 11 common clustering algorithms, including the Two-Step and the hierarchical clustering approach using the Ward's method that we used in our study, to a same dataset. Similar to our results, this study strongly supported the advantages of the Two-Step cluster approach over the classical clustering methods. However, although the Two-Step cluster

Table 6
Major UPA systems obtained from the cluster analysis and their similarities across the three West African cities of Kano, Bobo Dioulasso and Sikasso.

UPA system	Clusters			
	Kano	Bobo Dioulasso	Sikasso	Cross-location cluster number
Commercial gardening plus field crop-livestock (cGCL)	K1	B4	S2	1
Commercial gardening plus semi-commercial livestock (cGscL)	K2	–	–	2
Commercial livestock plus subsistence field cropping (cLsC)	K4	B1	S3	4
Commercial gardening plus semi-commercial field cropping (cGscC)	K3	B3	S4	3
Commercial field cropping (cC)	–	B2	–	5
Commercial gardening (cG)	–	–	S1	6

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Table 7
Congruency (%) between the manual expert classification and the classification obtained from the cluster analysis.

Groups based on manual expert classification	Groups based on cluster analysis																	
	cGCL[a]			cGscL			cGscC			cLsC			cC			cG		
	K[b]	B	S	K	B	S	K	B	S	K	B	S	K	B	S	K	B	S
GCL[c]	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC	0	0	0	0	0	0	0	0	0	100	100	100	0	0	0	0	0	0
GC	25	0	6	0	0	0	75	100	94	0	0	0	0	0	0	0	0	0
GL	0	0	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
C	0	0	0	0	0	0	0	0	0	100	0	100	0	100	0	0	0	0
L	0	0	0	100	0	0	0	0	0	0	100	0	0	0	0	0	0	0

[a] cGCL = commercial gardening + field crop livestock; cGscL = commercial gardening + semi-commercial livestock; cGscC = commercial gardening + semi-commercial field cropping; cLsC = commercial livestock + subsistence field cropping; cC = commercial field cropping; cG = commercial gardening.
[b] K = Kano; B = Bobo Dioulasso; S = Sikasso.
[c] GCL = garden + crop + livestock; LC = livestock + crop; GC = garden + crop; GL = garden + livestock; G = garden only; C = field crop only and L = livestock only.

approach automatically detects the optimal number of clusters, like the classical hierarchical approach, it provides opportunities for the researcher to subjectively affect the final classification. In our study, we explored up to seven-cluster solutions for each city and finally decided to retain the four-cluster solution. Köbrich et al. (2003) and Rischkowsky, Siegmund-Schultze, Bednarz, and Killanga (2006) demonstrated that in the hierarchical approach, objective numbers of clusters could be obtained by using the researcher's subjective judgment to rationally cut the hierarchical tree. We therefore agree with Emtage, Herbohn, and Harrison (2007) and Kostov and McErlean (2006) that some degree of subjectivity is always present in typology research. As shown in Table 7, the pre-grouping, based on the expert evaluation, was very close to the final outcome of the cluster analysis. This expert classification used the asset-based (garden size, field area and livestock numbers) criteria of diversity of UPA activities. Our results thus confirm that under certain circumstances, for instance when it is not possible to use cluster analysis, an expert's manual classification may be very useful.

4.2. Main findings

By applying multivariate analysis techniques, we were able to identify six different UPA farming systems across the three West African cities investigated. Three were common to all three cities: commercial gardening plus field crop-livestock, commercial livestock plus subsistence field cropping, and commercial gardening plus semi-commercial field cropping. The commercial gardening plus field crop-livestock system was predominant in Kano, the commercial livestock plus subsistence field cropping was predominant in Bobo Dioulasso whereas the commercial gardening plus semi-commercial field cropping was the prevailing system in Sikasso. The other identified UPA systems were location-specific and were characterized as commercial gardening plus semi-commercial livestock in Kano, commercial field cropping in Bobo Dioulasso and commercial gardening in Sikasso. These findings provide evidence that, beyond the previous site-specific classifications (Danso et al., 2002; Drechsel et al., 2006; Kessler, 2003), a regional approach may be successfully applied to deal with the complexity of the UPA farming systems.

Since it is based on multiple criteria, the typology developed in this study depicts much better UPA systems with respect to the diversity of the UPA activities and the relative contribution of each activity to the participant household's income than do the various single criterion classifications provided in previous studies (Asomani-Boateng, 2002; Danso et al., 2002; Kessler, 2003; Ruma & Sheikh, 2010; Schilter, 1991). Out of the six UPA farming systems identified in the present study, only the commercial gardening system was included in the three major categories of urban agriculture in West Africa as described by Drechsel et al. (2006). This system is considered as a typical feature of many West African cities and has been previously described for Bobo Dioulasso, Burkina-Faso (Centrès, 1996; Freidberg, 1997), for Cotonou, Benin (Brock & Foeken, 2006), for Lagos and Port-Harcourt, Nigeria (Ezedinma & Chukuezi, 1999), and for Accra, Ghana (Etuah-Jackson, Klaassen, & Awuye, 2001) where it has been identified as the dominant system (Danso et al., 2002). The commercial gardening plus semi-commercial field cropping was previously reported from Bamako (Eaton & Hilhorst, 2003). However, the different mixed systems identified in our study, which disclose the strong tendency for diversification of agricultural activities among West African UPA households, were poorly identified in previous studies and are not in agreement with the general perception that vegetable growing, field cropping and livestock keeping activities are undertaken by separate urban and peri-urban households (Veenhuizen Van & Danso, 2007). Similar combinations of UPA activities as obtained in our typology were recently reported in Niamey (Graefe et al., 2008). It is worth noting that, although small stock (e.g. chicken) was raised and staple crops (e.g. maize and millet) were grown mainly for home-consumption, the majority of the farms in our study were to some extent market-oriented. These findings are in agreement with Cour (2001) who argued that with the rise of food demand in cities, small scale farming in the West African Sahel will gradually shift from subsistence farming to commercial farming.

In their typology of rural farm households in Rwanda, Bidogeza et al. (2009) found that the age of the household head was a significant predictor of cluster membership. In a similar study in Kenya, Tittonell et al. (2010) also reported age of household head and size of the household as influential variables in cluster membership prediction. Interestingly, in our study, none of the variables related to personal attributes of the household head and to the household's socio-demography was found to be significantly predicting cluster membership. This may be explained by the fact that people involved in urban agriculture are more diverse in their origin and socio-economic conditions than rural farmers (Prain & Zeeuw de, 2007).

4.3. Implications for further research

Our typology enabled group membership identification and the statistical tests showed that most variables representing diversification of UPA activities had high discriminating power. This indicates that the identified groups were distinct and that our typology can be useful in further studies aiming at exploring differences in challenges, opportunities, resource uses efficiencies and innovation process among them and at identifying areas of potential cooperation between them. Furthermore, since it was based on a reduced set of household's socio-economic variables that can be easily and rapidly collected through a survey questionnaire with

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a limited set of questions, our typology is open to the inclusion of new households – within the three cities and beyond – into the identified groups.

5. Conclusions

Across the studied three West African cities, UPA households were classified into six different UPA farming systems using multivariate analysis techniques. Differences between the farming systems were determined largely by the diversity of the UPA activities, their individual contribution to the households' income and the households' resource endowments. Three of the identified UPA systems were common to the three cities. These findings confirm our hypothesis that a regional typology of UPA systems can be developed. This should serve as a starting point for in-depth analysis of characteristics, opportunities and problems of such livelihood systems, and form the basis for regional as well as location-specific recommendation domains. Our study thus provides a framework for further comprehensive bio-economic evaluation of the identified UPA systems and the development of appropriate technologies and policies that foster an ecologically sustainable, socially acceptable and economically profitable UPA in the Sudano-Sahelian zone of West Africa.

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