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Diversity and nutrient balances of urban and peri-urban farms in Ethiopia

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Abstract Urban and peri-urban agriculture (UPA) is important for food security in fast growing cities of developing countries. UPA also may have an important role in nutrient re-cycling at the interface of rural and urban areas. However, little is known about this role and whether it is different for different UPA systems. Here, we report on diversity and nutrient balances of UPA systems in three main cities of Ethiopia. Data collected from 425 households (Addis Ababa: 175, Adama: 126 Jimma: 124) were subjected to categorical principal component analysis and cluster analysis to classify the households. Four farm types per city and overall six: commercial livestock (cLS), commercial vegetable crop (cVC), subsistence field crop (sFC), cLScVC, cLScVCsFC and sVCsFC were identified across the three cities. Two types, cLS and cLScVC were common to the three cities. The farm types differed in resource endowment, income, soil fertility management and nutrient balances. cLS systems accumulated 450, 85 and 260 kg N, P and K ha^{-1} $year^{-1}$ and had 26% N and P and 15% K use efficiency, respectively while sFC systems depleted − 30 kg N and − 17 kg K ha^{-1} $year^{-1}$ and had 155% N and > 100% K use efficiency. There was little exchange of manure and crop residue between LS, FC and VC systems. To use the potential role of UPA in nutrient re-cycling, a directive that imposes LS systems to distribute their surplus manure resources to proximate FC and VC systems and improve their nutrient use efficiency should be put in place.

The original version of this article was revised. In Table 6, the asterisks (***) indicating the *P* values appeared under the column of use efficiency for N, under column of output for P and under column of input for K, should have been put under the columns of N, P and K balances.

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Introduction

Urbanization is one of the major social changes sweeping the globe (Akhmat and Bochun 2010) and currently, over half of the world's population lives in urban areas (Floater et al. 2014). Much of the current urbanization takes place in Africa and Asia, where urbanization started later compared to Europe and America (David et al. 2010). It leads to conversion of natural landscape into urban area, intensifies competition between land users and withdraws soil resources needed for food production (Blum 1997). The situation is particularly pervasive in some developing countries in Sub Saharan Africa (SSA) (FAO 2011; Makita et al. 2010), because most urban centers expand over their nations' most productive land (David et al. 2010). According to several projections, half of the population of Africa and Asia will live in urban areas by 2030 (Chen 2007). Among the rapidly developing countries, Ethiopia is the second populous country in Africa after Nigeria (UN 2015). In 2015, 20% of its population was living in urban areas. Its urban population growth is estimated at 6% a year (Haregewoin 2005), much higher than most African countries. Consequently, there is an increase in urban food demand that opened a door for farming in and around cities often called urban and peri-urban agriculture (UPA) (De Bon et al. 2010). Farmers use the advantages of available open spaces and market proximity (Zezza and Tasciotti 2010). UPA usually focuses on high value and perishable produce (Makita et al. 2010). It contributes to the livelihood of urban dwellers, providing jobs, food and income (Pearson et al. 2010). In Addis Ababa alone it supports the lives of over 51,000 families directly (Firdisa et al. 2007).

The sustainability of the UPA systems depends on their ability of producing healthy and safe food at affordable price while minimally affecting the environment (Nugent 2001). Currently, it is difficult to articulate strategies for UPA systems improvement because of its diversity and largely unknown socioeconomic and environmental performances (Chatterjee et al. 2015). Thus, data is needed on farm types and nutrient balances of UPA systems (Pacini et al. 2014). Here, we report on farm types and nutrient balances of UPA systems in three main cities of Ethiopia.

Materials and methods

Study sites

Three main cities in Ethiopia: Addis Ababa, Adama and Jimma were selected for this study (Fig. 1). They have a total population of 3.1, 0.3 and 0.2 million, and a population growth rate of 3.8, 4.5 and 3.0% per year, respectively (Haile Mariam and Adugna 2011). Addis Ababa (9°1′48″N, 38°44′24″E) is the capital city of the country. It is situated at an altitude of 2300–3000 m.a.s.l. Minimum and maximum daily temperatures are 10.7 and 23 °C, respectively, and mean annual rain fall is 1165 mm. Barley, wheat and pulses are the staple crops.

Adama (8.54°N, 39.27°E) is the commercial centre near the main port. It is situated at an altitude of 1700 m.a.s.l. Minimum and maximum daily temperatures are 13.3 and 27.8 °C, respectively, and mean annual rainfall is 809 mm. Wheat, barley, teff and pulses are the common crops. Jimma (7°40′N, 36°50′E) is the commercial centre of Southwestern Ethiopia. It is situated at an altitude of 1780 m.a.s.l. Minimum and maximum daily temperatures are 12 and 27 °C, respectively, and mean annual rainfall is 1510 mm. Coffee, tea, spices, teff and maize are the main crops. According to the information of the city administration, Addis Ababa has ten sub-cities. The majority of UPA farms are found in five sub-cities: Akaki-Kaliti, Bole, Kirkos, Kolfe-Keranio and Nifa-silk-Lafto and were selected for this study. In Adama and Jimma all the districts were selected.

Data collection

UPA households were selected through the snowball sampling technique (Dossa et al. 2011). According to Israel (1992), a sample size of 200 is appropriate for farmers' population between 5000 and 10,000 at 95% confidence level and 7% precision level. The current UPA farmers' populations of Addis Ababa, Adama and Jimma are estimated between 1000 and 9000 according to the information obtained from the cities urban agriculture offices. Thus, to get representative data of the main agricultural activities, 175 households

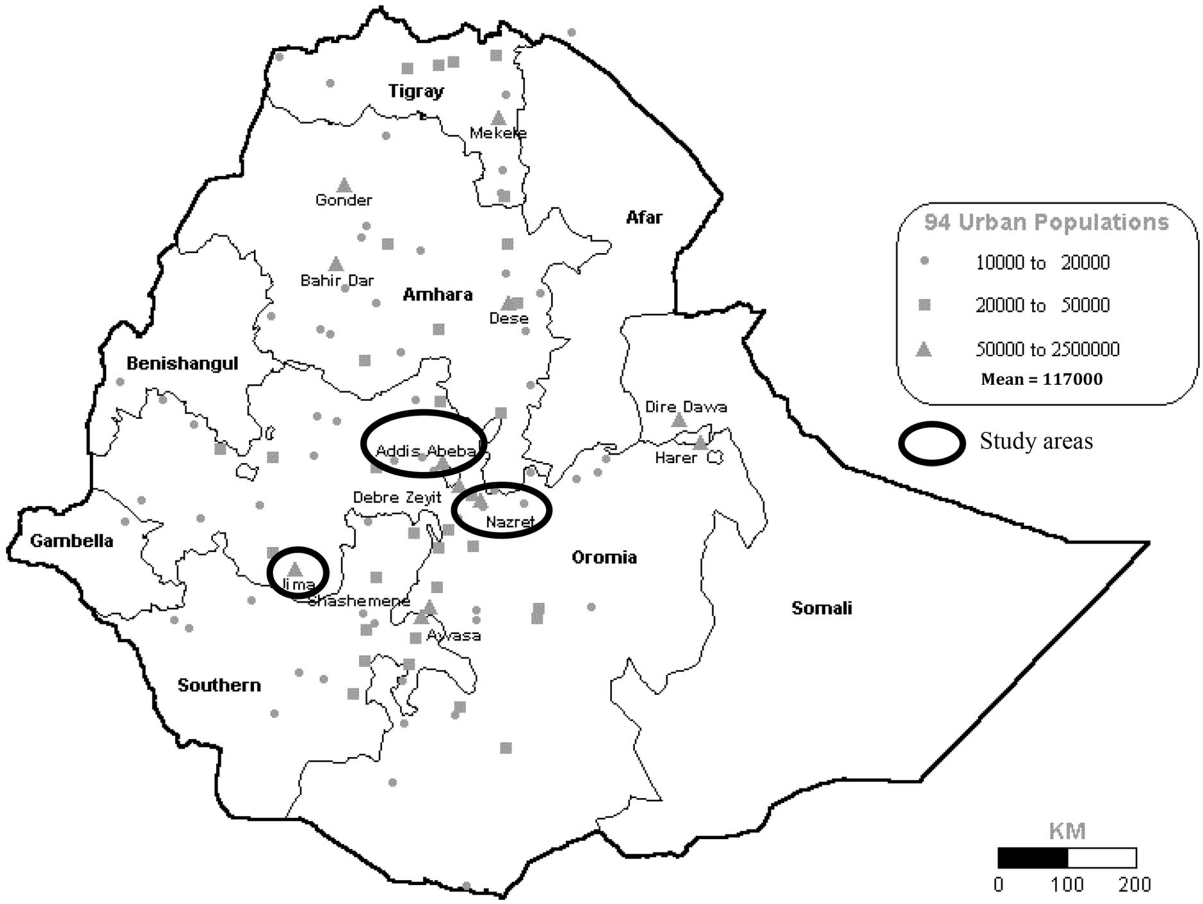

Fig. 1 Map of major urban areas in Ethiopia, including the study areas Addis Ababa, Adama (Nazret) and Jimma with high population (50,000–2,500,000) *Source* UNDP (1996) Major urban areas and regions of Ethiopia. https://goo.gl/images/Sv5H1T. Accessed 17 August 2017

in Addis Ababa (64 livestock oriented, 61 vegetable oriented and 50 field crop oriented farmers), 126 in Adama (56 livestock, 36 vegetable and 34 field crop farmers) and 124 in Jimma (53 livestock, 34 vegetable and 37 field crop farmers) were interviewed using a structured questionnaire. Prior to the actual survey, a draft version was tested on 15 households and revised subsequently. The questionnaire contained questions such as the socioeconomic characteristics; agricultural practices; resource endowment; use of own agricultural waste, types and quantities of inputs and outputs flows and finally constraints of UPA farms (see supplementary information). The interviews were conducted by four PhD students of Addis Ababa University and four MSc students of Jimma University between March and August 2014. The students are native to the area and spoke the local language. They were trained by the first author for 1 week.

Quantification of partial nutrient balances and nutrient use efficiencies

Partial nutrient balances of farms result from processes and flows managed by the farmer and are calculated as the net differences of the main easily manageable nutrient inputs (fertilizers and feed) and outputs (farm products) flows (Abdulkadir et al. 2013; van Beek et al. 2016). For increasing the precision in the quantification of the partial nutrient balances, data was collected in two rounds. In round one, input flows (mineral fertilizers, organic fertilizers, purchased seeds, organic feed and concentrates) were quantified by asking the farmer about the use of these inputs at the begining of the season. In the second round, output flows (crop products, residues and animal products) leaving the farm were quantified by asking the farmer after harvest, at the end of the growing season. Estimates of animal manure production were based on information provided by the farmer and additional literature data (Jackson and Mtengeti 2005). The quantity of manure produced by each livestock species (cattle, sheep and goat) was estimated using daily dry matter and nitrogen, phosphorus and potassium production rates per tropical livestock unit, for each of the species. For commercial livestock farms we assumed 100% recovery of the total manure produced, since the animals are entirely kept in the stable, but for subsistance livestock we assumed 43% of the manure is recovered in the stable and 57% was lost outside the farm during grazing. For grazing animals, the feed intake during grazing was considered to balance the loss of manure and urine outside the farm during grazing (Abdulkadir et al. 2013). Data on the nutrient (N, P, K) contents of harvested crop products, crop residues, milk and manure were obtained from literature (Alvarez et al. 2014; Wang et al. 2016). For quantification of nitrogen (N), phosphorus (P) and potassium (K) input and output flows, the mass of inputs and outputs were multiplied by their dry matter contents and N, P, K contents (Bekunda and Manzi 2003), (Eq. 1).

$$F = \sum_{i=1}^{n} QiDiCi \quad (1)$$

where, F is the quantity of input or output flows of N or P or K for 1 year; n is the number of nutrient inputs and outputs in a year; Q is the quantity of inputs (organic and inorganic) or outputs, obtained from household survey; D is the dry matter content of inputs or outputs; C is content of N or P or K in inputs or outputs obtained from literature review. Then, partial nutrient balances were calculated as the difference between input and output flows (Eq. 2).

$$PNB_F = [(I1_F + I2_F) - (O1_F + O2_F)] \quad (2)$$

where, PNB is the partial nutrient balance; F is the nutrient (N or P or K); $I1_F$ and $I2_F$ are inputs of inorganic (I1) and organic (I2) nutrients (inorganic fertilizer, compost, concentrate, organic feed) and $O1_F$ and $O2_F$ are nutrients outputs in harvested crop, residue, milk and manure. Finally, nutrient (N, P and K) use efficiencies of farms were calculated according to Wang et al. (2008) by dividing the quantity of nutrient output by input and multplying by 100 (Eq. 3).

$$NUE = \frac{Nutrientoutput(O1_F + O2_F)}{Nutrientinput(I1_F + I2_F)} * 100 \quad (3)$$

where, NUE is the nutrient (N, P and K) use efficiency, in %.

Data analysis

Data was checked, cleaned and subjected to Categorical Principal Component Analysis (CATPCA) as the dataset contained mixed variables (nominal, ordinal and metric). CATPCA was used to explore the relationships between variables and reduce large number of variables into smaller number of principal components (Pacini et al. 2014). CATPCA was done using the 23 variables derived from the surveys (Table 1). A component is considered reliable, if it contains a minimum of four variables with component loading score > 0.6, because a variable with the higher loading score on a given component is the most influential variable, and contributing most to the variation accounted for that component (Abdulkadir et al. 2012; Dossa et al. 2011). Using this criterion, two principal components with loading score > 0.6 were found per city (Table 2). Two-step cluster analysis (CA) was used to classify the households into clusters. Before running CA, visual binning procedure was performed to convert continuous variables into nominal variables and reduce the weight of categorical variables which could be higher at the expense of continuous variables (Dossa et al. 2011). Then, two-step cluster analysis was performed using component scores extracted from CATPCA and the variables with component loading score > 0.6. The number of UPA clusters was fixed for each city using the Bayesian Information Criterion (BIC). A silhouette measure of cluster cohesion and separation, used for measuring the quality of clustering was between 0.6 and 0.7 and showed a good clustering quality (Dossa et al. 2011). Cluster numbers generated from CA were used to identify which household belongs to which cluster, and a cluster name was assigned to each. ANOVA was performed to test the significant differences in resources endowment, income and nutrient balances between UPA clusters per city. Multiple linear

Table 1 Description of farm management and socio-economic variables used in the CATPCA of 175, 126 and 124 UPA households in Addis Ababa, Adama and Jimma, respectively

Variables	Description and units
A_HH	Age of UPA of HH[a] (years)
S_HH	Sex of HH (female, male)
ACT_F	Active labor force between 15 and 65 (years)
F_EXP	Farming experience of HH in UPA (years)
NP_FCVC	Field crop (FC) and vegetable crop (VC) plots owned by a HH (number)
TLD_SZ	Total land size owned by the HH (ha)
N_DRC	Number of dairy cows (number)
TLS_TLU	Total number of livestock production (TLU)[b]
INC_FC	Income from FC (ETB)[c]
INC_VC	Income from VC (ETB)
INC_MK	Income from milk (ETB)
INC_LS	Income from livestock (LS) (ETB)
INC_UPA	Income from urban and peri urban agriculture (ETB)
PROB_F	HH primary farming objective (consumption, sales)
INV_LS_P	HH involvement in (peri) urban LS production (yes, no)
INV_DR_F	HH involvement in (peri) urban dairy farming (yes, no)
INV_VC_P	HH involvement in (peri) urban VC production (yes, no)
INV_FC_P	HH involvement in (peri) urban FC production (yes, no)
OW_VCFC_P	Use of own waste for soil fertility management (yes, no)
VC_SR_INC	Sales of VC as source of income of HH (yes, no)
MK_SR_INC	Sale of milk as source of income of HH (yes, no)
HCT_IN_FCP	Cost of inputs for FC production (high, medium, low)
HCT_FE_LSP	Cost of feed for LS production (high, medium, low)

[a] *HH* household head

[b] *TLU* tropical livestock unit, a hypothetical animal of 250 kg live weight; TLU conversion factors used: cattle = 0.8, sheep and goats = 0.1, donkey = 0.5, and poultry = 0.01

[c] Ethiopian Birr (1000 ETB = 43 US$)

regression was conducted using socioeconomic variables versus nutrient balances of main UPA farm types. We used SPSS statistics version 22 for all types of data analysis.

Results

Categorical principal component analysis (CATPCA)

Two reliable principal components representing the information in the original variables were obtained for each city. The first component accounted for 31% of variance in Addis Ababa, 34% in Adama and 40% in Jimma UPA systems. The second component accounted for 22, 15 and 11% of variances in the UPA systems of the three cities, respectively.

The most influential variables with high component loading scores were related to the main UPA activities: livestock (LS), vegetable crops (VC) and field crops (FC) production. For instance, for Addis Ababa UPA, income from VC was strongly related with principal component one, while income from FC and LS was strongly related with principal component two. For Adama, income from VC was also strongly related with principal component one. In contrast, number of LS (TLU) and income from LS was strongly related with principal component one for Jimma. These variables with high loading score (> 0.6) on either of the principal components contributed greatly to the variation explained by the component, and they are influencial variables for the classification of the UPA households into clusters. Cronbach's alpha values for both components were high per city (Table 2); values above 0.7 indicate high internal consistency of variables and homogeneity of UPA systems per cluster. Vectors pointing in the same direction in Fig. 2 were correlated and their length indicated that they are the most influential variables. High Eigenvalues of component one and two in Table 2 indicated, large percentage of variance was explained by the components.

Table 2 Component loadings of socioeconomic variables used for CATPCA in Addis Ababa, Adama and Jimma cities (Variables are explained in Table 1)

Variables	Addis Ababa (n = 175)		Adama (n = 126)		Jimma (n = 124)	
Dimensions	1	2	1	2	1	2
A_HH[a]	.328	.119	− .388	.094	− .203	.292
S_HH	.017	.035	.296	− .069	− .038	.182
ACT_F	.334	.087	− .092	.034	− .144	.286
F_EXP	.162	− .274	− .664	− .199	.281	.455
PROB_F	− .148	.655	.317	.458	− .521	− .466
INV_LSP	− .608	− .481	− .578	.111	.704	.256
INV_DRF	− .497	− .498	− .296	.046	.697	.230
INV_VCP	.915	− .300	.836	− .383	− .664	.490
INV_FCP	− .221	.735	.783	.404	− .737	− .059
NF_FCVC	− .798	.302	− .812	− .046	.866	.076
TLD_SZ	− .082	− .551	− .649	− .361	.556	.069
N_DRC	.496	.575	.274	− .035	− .709	− .350
TLS_TLU	.511	.556	.277	.237	− .606	− .389
OW_FCVCP	.605	− .121	.357	.289	− .607	.026
INC_FC	.141	− .654	− .326	− .457	.471	− .292
VC_SR_INC	.892	− .310	.843	− .411	− .648	.549
INC_VC	− .684	.204	− .719	.467	.520	− .226
MK_SR_INC	− .453	− .603	− .428	− .245	.813	.299
INC_MK	.463	.593	.395	.322	− .646	− .195
INC_LS	.490	.685	.426	.398	− .685	− .188
INC_UPA	.437	.582	.202	.501	− .685	− .188
HCT_IN_FCP	.293	.345	.558	.380	− .710	.081
HCT_FE_LSP	− .426	− .389	− .323	.220	.692	.172
Cronbach's Alpha	0.93	0.88	0.94	0.81	0.95	0.72
Total Eigenvalue	9.76	6.74	10.60	4.55	12.67	3.29
Total % of variance	31.49	21.74	34.21	14.68	40.86	10.61

Classification of UPA households

Two-step cluster analysis yielded four distinct farm types per each city. Due to similarities of some farm types between the cities, six different farm types were distinguished across the cities of Addis Ababa, Adama and Jimma in Ethiopia (Table 3). Among these, subsistence field crop farm (sFC) was commen to Addis Ababa and Adama, and mixed commercial livestock and vegetable crop and subsistence field crop (cLScVCsFC) was commen to Adama and Jimma. Two farm types, commercial livestock (cLS) and commercial livestock and vegetable crop (cLScVC) were commen to the three cities but commercial vegetable crop farm (cVC) was uniqe to Addis Ababa while subsistence vegetable crop and field crop (sVCsFC) was unique to Jimma. Farms are categorized as commercial or subsistence based on their primary farming objective (Table 4).

cLS: Cluster one at Addis Ababa and Adama and cluster four at Jimma UPA

This farm type is categorized as commercial livestock (cLS), because the primary farming objective was marketing for 100% farms in cluster 1 at Addis Ababa, 86% in cluster 1 at Adama and 100% in cluster 4 at Jimma (Table 4). Farms in this cluster are located in urban residential areas. cLS is done by 36% of farmers interviewed at Addis Ababa, 28% at Adama and 40% at Jimma (Table 3). It is the most important economic activity with the highest income across the cities (Table 5).

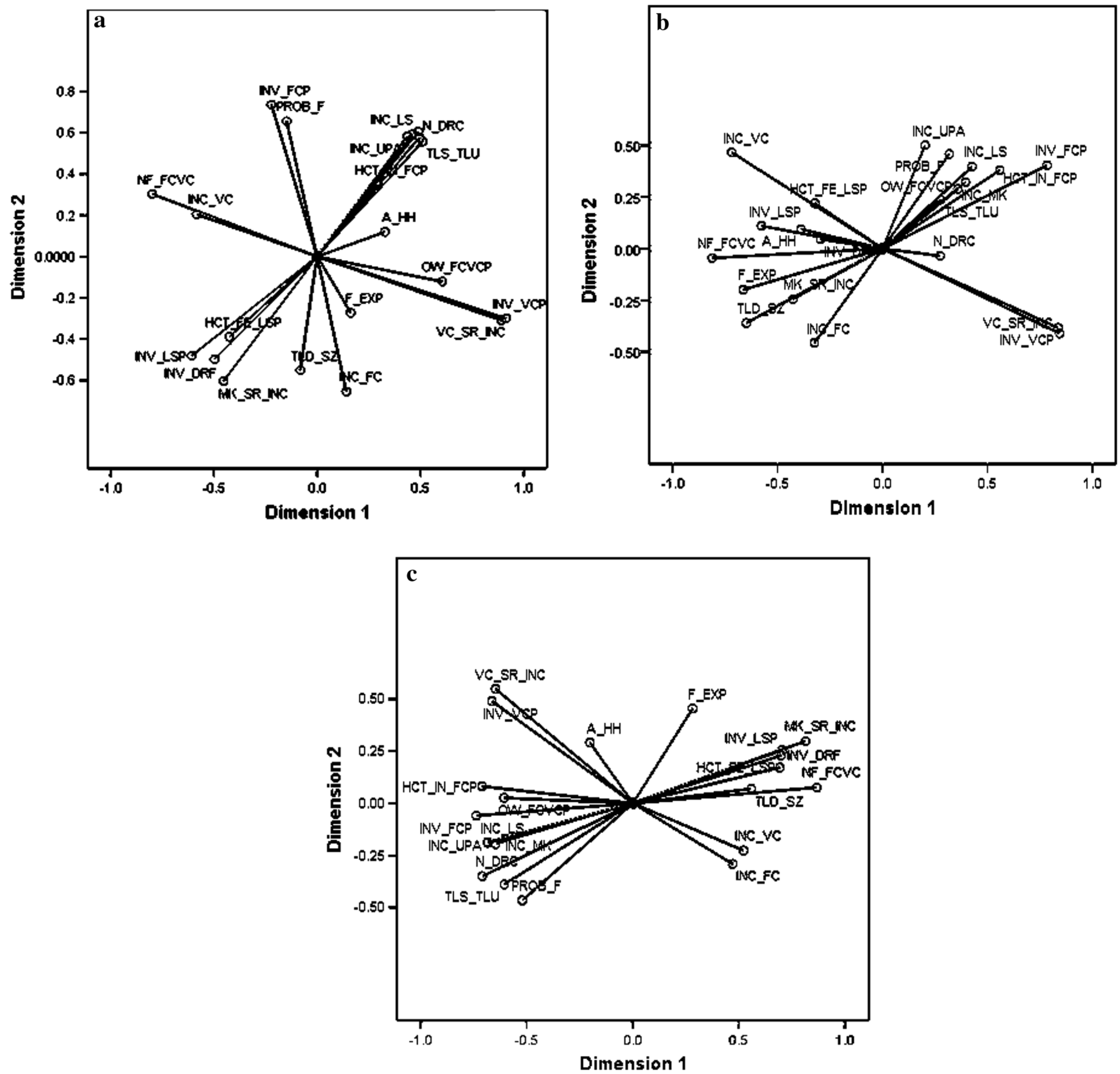

Fig. 2 Plots of component loadings for **a** Addis Ababa (n = 175), **b** Adama (n = 126) and **c** Jimma (= 124) UPA depicting the relationship among most influential variables described in Tables 1 and 2

cLScVC: Cluster three at Addis Ababa and Jimma and cluster two at Adama UPA

This farm type is categorized as commercial livestock and vegetable crop (cLScVC), as the primary farming objective was marketing for 100% of the farms in cluster 3 at Addis Ababa and Jimma and for 79% farms in cluster 2 at Adama. At Addis Ababa 100% of cLScVC farms were involved in LS and 96% in VC production (Table 4). cLS farms were located in the urban areas and cVC farms were located in urban and peri-urban areas near rivers. cLScVC farming is done by 15% of households interviewed at Addis Ababa, 22% at Adama and 10% at Jimma (Table 3).

cLScVCsFC: Cluster four at Adama and two at Jimma UPA

Marketing was the primary farming objective for 63 and 67% of the farmers in cluster 4 at Adama and

Table 3 Classification of UPA farms and the distribution of households (HH) across the four clusters at Addis Ababa, Adama and Jimma

Clusters of UPA	Addis Ababa (n = 175)		Adama (n = 126)		Jimma (n = 124)	
	Cluster name	% HH	Cluster name	% HH	Cluster name	% HH
Cluster 1 (one)	cLS	36	cLS	28	sVCsFC	28
Cluster 2 (two)	sFC	22	cLScVC	22	cLScVCsFC	22
Cluster 3 (three)	cLScVC	15	sFC	26	cLScVC	10
Cluster 4 (four)	cVC	27	cLScVCsFC	24	cLS	40

cLS commercial livestock farms, *sFC* subsistence field crop farms, *cVC* commercial vegetable crop farms, *cLScVC* commercial livestock and commercial vegetable crop farms, *sVCsFC* subsistence vegetable crop and subsistence field crop farms, *cLScVCsFC* commercial livestock, commercial vegetable crop and subsistence field crop farms

cluster 2 at Jimma. It is located in urban and per-urban areas and done by 24% of the farmers at Adama and 22% at Jimma (Table 3). At Adama, 57% of the cLScVCsFC farms were involved in both LS and VC and 91% in FC production in cluster 4 (Table 4).

cVC: Cluster four at Addis Ababa UPA

This farm type is categorized as commercial vegetable crop farm (cVC), and uniquely identified at Addis Ababa UPA. It is practiced in peri-urban areas by 27% of the households interviewed at Addis Ababa (Table 3). Here, 100% of the cVC farms produce VC for the market (Table 4).

sFCs: Cluster two at Addis Ababa and cluster three at Adama UPA

This farm type is categorized as subsistence FC (sFC) farming, as the primary farming objective was consumption for 93% of the farms in cluster 2 at Addis Ababa and for 65% of the farms in cluster 3 at Adama. At Addis Ababa 100% of the sFC farms and at Adama 97% of the sFC farms produced FC for own consumption (Table 4). It is done in peri-urban areas by 22% of the farmers interviewed at Addis Ababa and by 26% at Adama (Table 3).

sVCsFC: Cluster one at Jimma UPA

This farm type is identified only at Jimma and categorized as subsistence VC and FC (sVCsFC) farming; home consumption was the primary farming objective for 80% of the farmers in this cluster. Here, 100% of the farmers produce FC and 92% also produce VC (Table 4). This farm type is done in peri-urban areas by 28% of the farmers interviewed at Jimma (Table 3).

Main farm characteristics of UPA clusters across the cities

UPA clusters had different agricultural waste and fertility management (Table 4). At Addis Ababa 100%, at Adama 86% and at Jimma 92% of the cLS farmers didn't use their manure for soil fertility management because they didn't produce feed on farm due to shortage of land (Table 5). High cost of feed was a constraint for 67% of the cLS farmers at Addis Ababa, for 62% at Adama and for 88% of the cLS farmers at Jimma. Similarly, many sFC farmers (28–79%) didn't use their crop residues and LS manure for soil fertility management due to competing demand on biomass for feed and fuel. High cost of nutrient inputs was a constraint for 62–77% of the sFC farmers.

There were significant differences among the UPA clusters per city in households' resource endowment and income (Table 5). In Addis Ababa, farm area and number of fields per farm were small. Highest income per household was obtained from cLS. Vegetable crop (VC) and field crop (FC) gave relatively low income. Farms with relatively large area but no marketable produce (cluster 2, sFC) had also low income. In Jimma, farm area and number of fields per farm were larger than Addis Ababa and Adama. Interestingly, cLS farms in Jimma had a lower number of LS compared to cLS farms in Addis Ababa, but income from LS was higher at Jimma than Addis Ababa. cLS farms at Jimma had higher income than cLS farms at Addis Ababa and Adama because they owned relatively

Table 4 Distribution of households in percent across the four UPA clusters listed in Table 3, in terms of the main farm characteristics, at Addis Ababa, Adama and Jimma

Main farm characteristics	Addis Ababa Clusters				Adama Clusters				Jimma Clusters				χ^2
	1 cLS (n = 63)	2 sFC (n = 39)	3 cLScVC (n = 25)	4 cVC (n = 48)	1 cLS (n = 35)	2 cLScVC (n = 28)	3 sFC (n = 33)	4 cLScVCsFC (n = 30)	1 sVCsFC (n = 35)	2 cLScVCsFC (n = 27)	4 cLScVC (n = 13)	4 cLS (n = 49)	
Percentage of households involved													
Marketing as primary objective	100	7	100	92	86	79	35	63	20	67	100	100	***
FC production	0	100	20	6	0	0	97	91	100	77	0	0	***
VC production	0	0	96	100	0	50	0	57	92	100	62	0	***
LS production	100	36	100	2	100	89	37	57	6	52	100	100	***
Waste, residue use for SFM, Yes	0	21	81	56	14	28	43	47	72	74	33	8	***
No	100	79	19	44	86	72	57	53	28	26	67	92	***
High cost of inputs for FC	0	62	44	42	0	0	67	60	77	67	54	0	***
High cost of feed for LS	67	10	54	0	62	26	12	23	0	22	69	88	***

χ^2 represents the Chi square values; Chi square was used to compare categorical variables

SFM Soil fertility management

*** Denotes significant difference at $P < 0.01$

large size of land for LS farming and so had lower cost of animal feed input.

Partial nutrient balances and nutrient use efficiencies

Partial N, P and K balances differed significantly ($P < 0.001$) between the four farm types per each city (Table 6). At Addis Ababa, Adama and Jimma the mean N balance was negative for FC farms (− 30 kg ha^{-1} year^{-1}), but positive for VC (19 kg ha^{-1} year^{-1}) and LS (453 kg ha^{-1} year^{-1}) farms. The mean P balance was positive in all farm types across the cities. The mean K balance was also positive for LS farms (264 kg ha^{-1} year^{-1}), but negative for FC (− 17 kg ha^{-1} year^{-1}) and VC (− 70 kg ha^{-1} year^{-1}) farms across the cities (Table 6). The variability of nutrient balances was high within a farm type (Figs. 3–5).

The nutrient use efficiency (NUE) also differed across the three cities. The mean N use efficiency ranged from 26 to 155% across the farm types of the three cities with the minimum in LS farms and the maximum in FC farms. Similarly the mean P use efficiency ranged from 26 to 55% with the minimum in LS farms and the maximum in FC farms. The mean K use efficiency ranged from 15 to more than 100% (Table 6).

Relationships between farm characteristics and nutrient balances

The results of multiple regression analysis are summarized in Table 7. Socioeconomic variables explained 28% of the variances in N balance and only 10% of the variances in P balance for the main farm types of Addis Ababa. Similarly, 13% of the variances in N balances and 10% of the variances in P balances were explained for Adama, and 33% of the variances in both N and P balances were explained for Jimma UPA.

Discussion

Characteristics of urban and peri-urban farms

Four UPA farm types were identified per city and six in total across the three cities (Table 3). The farm

Table 5 Resource endowment and income of households per farm per year across the four UPA clusters in Addis Ababa, Adama and Jimma

Main farm characteristics	Addis Ababa Clusters				Adama Clusters				Jimma Clusters			
	1 cLS (n = 63)	2 sFC (n = 39)	3 cLScVC (n = 25)	4 cVC (n = 48)	1 cLS (n = 35)	2 cLScVC (n = 28)	3 sFC (n = 33)	4 cLScVCsFC (n = 30)	1 sVCsFC (n = 35)	2 cLScVCsFC (n = 27)	4 cLScVC (n = 13)	4 cLS (n = 49)
No of FC and VC fields	0.38^{c}	1.13^{b}	2.04^{a}	1.71^{a}	0.06^{b}	3.1^{a}	3.2^{a}	3.2^{a}	3.8^{a}	3.1^{a}	1.9^{b}	2^{b}
Land size (ha)	0.11^{c}	1.71^{a}	0.98^{b}	0.76^{b}	0.03^{c}	0.9^{b}	1.5^{a}	1.1^{b}	1.6	1.96	0.8	0.5
Livestock (TLU)	10.4^{a}	1.74^{c}	6^{b}	0.04^{c}	7.4^{a}	2^{b}	3.4^{b}	3.1^{b}	0.8^{c}	3.2^{b}	3.7^{b}	8.2^{a}
Income from FC (ETB)	0	11,951	98	408	0	0	13445^{a}	5595^{b}	1420	3038	0	0
Income from VC (ETB)	0	256^{b}	23578^{a}	24856^{a}	0	11,744^{b}	303^{b}	29522^{a}	4457^{a}	5371^{a}	6031^{a}	0^{b}
Income from LS (ETB)	172368^{a}	4779^{c}	74791^{b}	0	162378^{a}	18037^{b}	13810^{b}	16942^{b}	94^{b}	11050^{b}	29573^{b}	206588^{a}

ANOVA was used to compare continuous variables. Means with different letters within rows are statistically different using LSD test at $P < 0.05$

ETB ethiopian birr (1000 ETB = 43 US$)

Table 6 Mean partial balances (kg ha^{-1} year^{-1}) and use efficiencies (%) of nitrogen (N), phosphorus (P) and potassium (K) at farm level for three main farm types in Addis Ababa, Adama and Jimma

Cities	Flows	N				P				K			
	Farm types[a]	In put	Out put	Use efficiency (%)	Balance[b]	In put	Out put	Use efficiency (%)	Balance[b]	In put	Out put	Use efficiency (%)	Balance[b]
Addis Ababa	FC	62	87	140	− 25[c]	30	13	43	17[c]	1	16	1600	− 15[b]
	VC	106	87	82	19[b]	38	10	26	28[b]	11	80	727	− 69[c]
	LS	581	155	27	426[a]	113	29	26	84[a]	234	44	19	190[a]
Adama	FC	34	64	180	− 30[c]	18	10	56	8[c]	1	13	1300	− 12[b]
	VC	93	79	85	14[b]	30	9	30	21[b]	1	78	7800	− 77[c]
	LS	582	112	19	470[a]	107	25	23	82[a]	373	38	10	335[a]
Jimma	FC	78	113	145	− 35[c]	34	22	65	12[c]	2	27	1350	− 25[b]
	VC	104	80	77	24[b]	35	9	26	26[b]	6	70	1167	− 64[c]
	LS	669	206	31	463[a]	125	37	30	88[a]	324	56	17	268[a]
P value					***				***				***

Means of nutrient balances with different letters within columns per city are statistically different

*** Denote significant differences at $P < 0.01$

[a]*FC* field crop farms; *VC* vegetable crop farms, *LS* livestock farms

[b]Partial balance = $\sum$ Farmer managed IN flows − $\sum$ Farmer managed OUT flows. Field level flows were aggregated at farm level and then averaged per farm type; ANOVA was used to compare means for partial nutrient balances of the farm types per city

types identified include a wide diversity of the UPA activities, since they are based on multiple variables. Dossa et al. (2011), also reported that typology classification based on multiple variables performs better than classification based on a single criterion. Farms grouped in one typology are similar to each other in multiple variables than a sigle variable.

The UPA farm types were different notably in primary farming objectives, income, resource endowment, use of agricultural waste for soil fertility management and nutrient balances. The primary objective of farming was marketing for 75% of the UPA clusters per city (Table 4). Dossa et al. (2011) also found that the majority of the UPA farms in their study were market oriented. Yet, for 25% of the UPA farmers the primary objective of farming was home consumption and marketing was the second objective. These UPA farmers are resource-poor small holder farmers with lack of capital and knowledge and therefore, produce FC with minimum inputs.

Livestock, vegetable and field crop production are common UPA activities in many developing countries (Abdulkadir et al. 2012; Pasquini et al. 2010). Among the six farm types identified, LS farms were economically the most important as they generate the highest income. Comparing LS with FC, Castel et al. (2010) reported also higher income for LS farms. The majority of LS farms in this study were land-less, and almost all feeds were scavenged and/or purchased from other regions. Condon et al. (2010) and Nigussie et al. (2015) also reported shortage of land as the main constraint for urban farmers. Land is very expensive in urban areas, and priority is given to residential areas and commercial centers demanded by the rapidly growing urban population at the rate of 3.8, 4.5 and 3.0% per year in Addis Ababa, Adama and Jimma, respectively (Haile Mariam and Adugna 2011). The remaining five farm types were mixed LS, VC and FC farming systems with relatively larger land holding (1.2 ha on average; Table 5). The mixed systems identified in our study disproved the traditional perception that LS, VC and FC productions are carried out by separate households (Van Veenhuizen and Danso 2007). Instead, we found that most farmers were involved in mixed UPA activities with different levels of intensification. Graefe et al. (2008) and Dossa et al. (2011) also reported mixed UPA activities with diversified income sources.

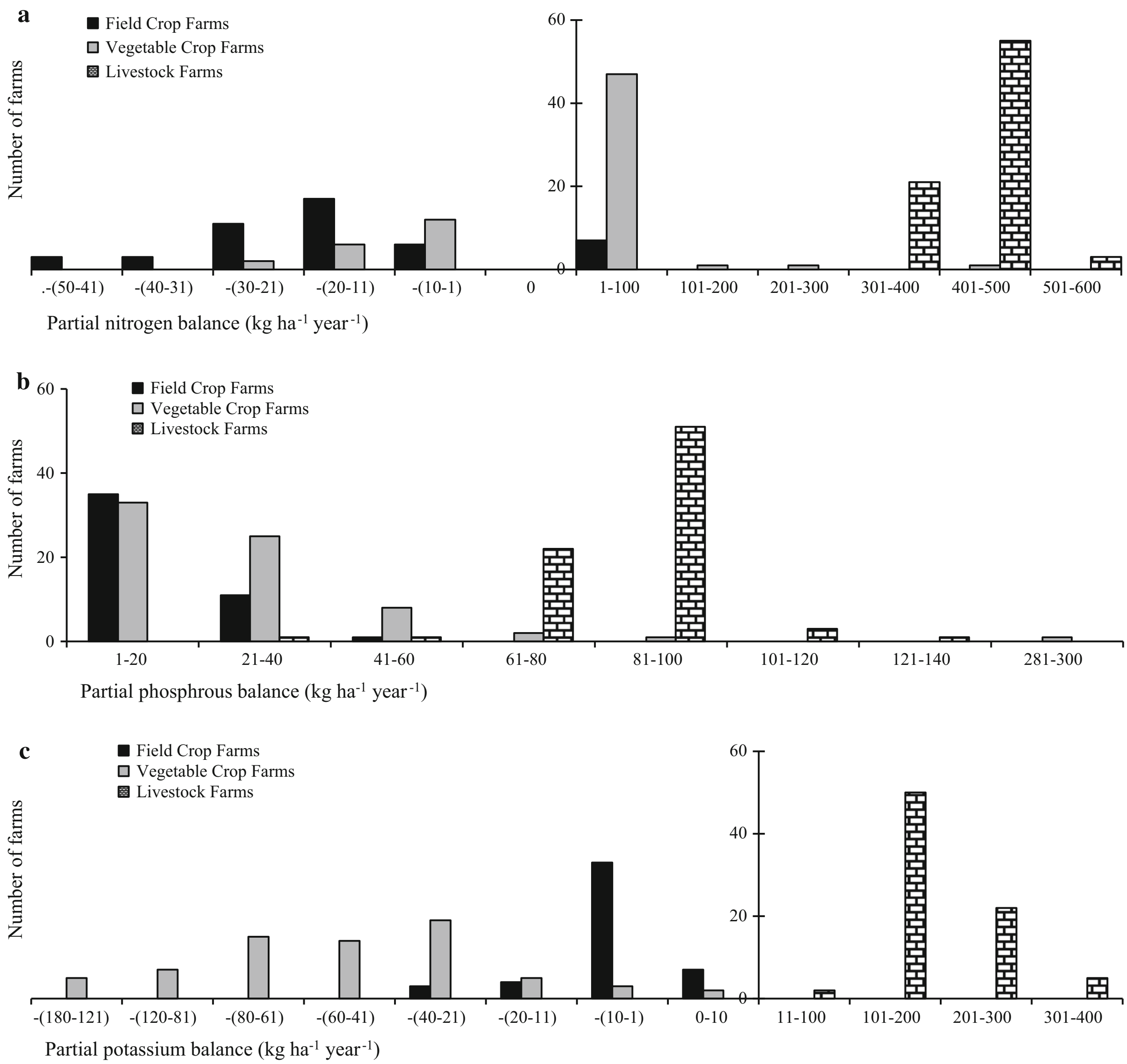

Fig. 3 Frequency distribution of partial **a** (nitrogen), **b** (phosphorus) and **c** (potassium) balances for the different farm types at Addis Ababa city

Agricultural waste and soil fertility management

Use of agricultural wastes, crop residues and manure for soil fertility management was limited and different between the UPA clusters (Table 4). The inorganic fertilizers di-ammonium phosphate (DAP) and urea were the main external sources of plant nutrients because these are available on the market. This is in agreement with Baudron et al. (2014) and Nigussie et al. (2015). More than 50% of the UPA farmers didn't use agricultural waste for soil fertility management at least for the following reasons. First, close to the urban centers, where cLS farms were the dominant farming system, the farmers have no land. Therefore, they simply dumped animal manure in ditches and surroundings or left it unmanaged on the ground, while some dung was used as biofuel. Nigussie et al. (2015) also reported that a large quantity of waste was

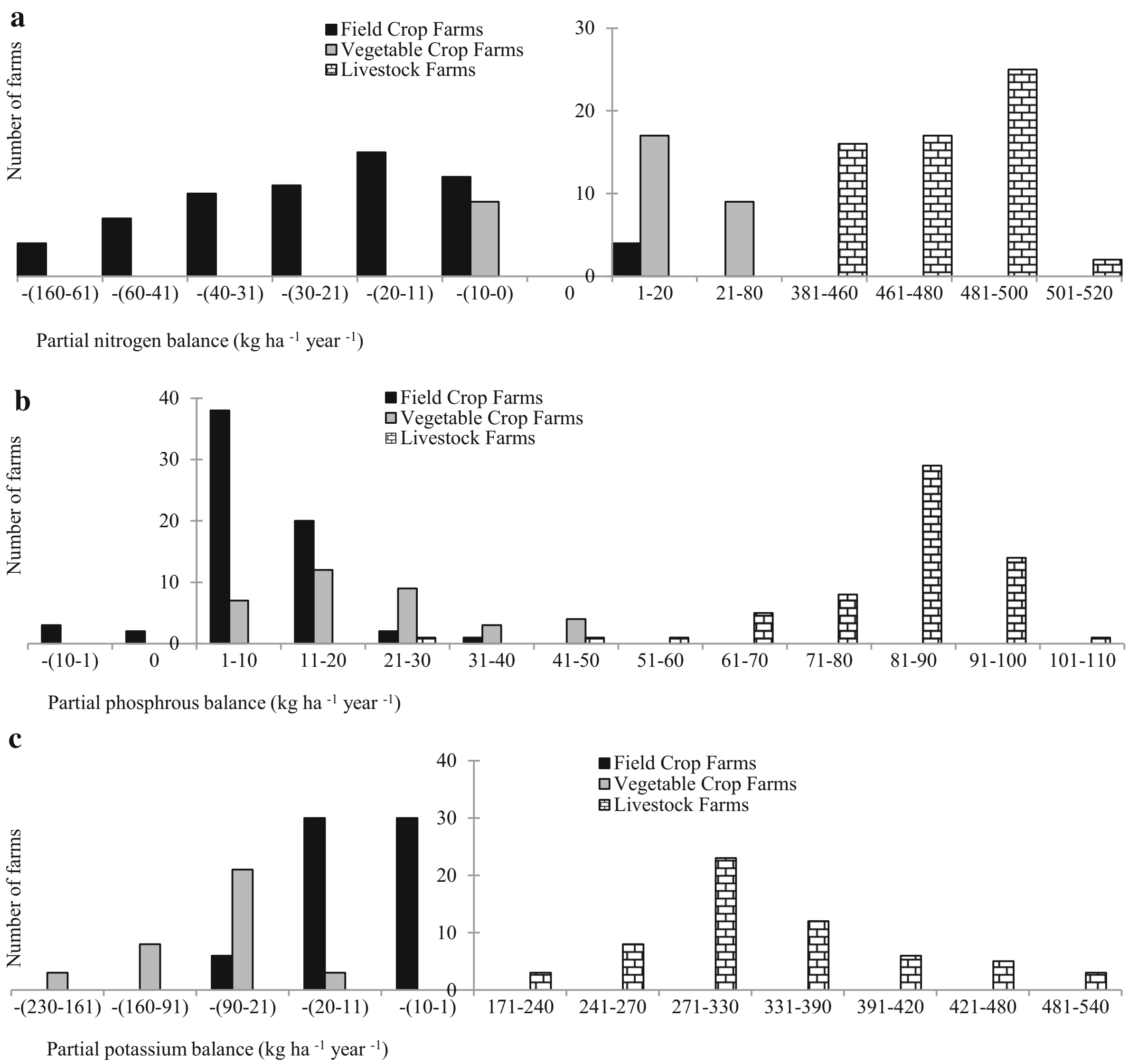

Fig. 4 Frequency distribution of partial **a** (nitrogen), **b** (phosphorus) and **c** (potassium) balances for the different farm types at Adama city

dumped in landfills in urban areas. Second, in subsistence field crop (sFC) and subsistence vegetable crop (sVC) farms, the options to use agricultural waste for soil fertility management were limited due to low levels of crop production and high biomass demand for feed and fuel. This maintains a vicious circle of low inputs of organic amendments and low outputs of crop residue. Competition between uses (feed, energy, soil fertility) for crop residues and manure has been reported also for other countries (Baudron et al. 2014; Jaleta et al. 2014; Valbuena et al. 2015). Most sFC farms had relatively large farm size (Table 5) but the crop fields are located far away from the homestead. This is one of the barriers for using external nutrient sources; the cost of transporting manure from landless cLS farms in urban areas to crop fields in peri-urban areas is high. The costs of inorganic fertilizers for use in crop fields is also relatively high. Consistent with this, Nigussie et al. (2015) reported FC farmers used over 75% manure for fuel and 80% crop residues for feed at Addis Ababa UPA.

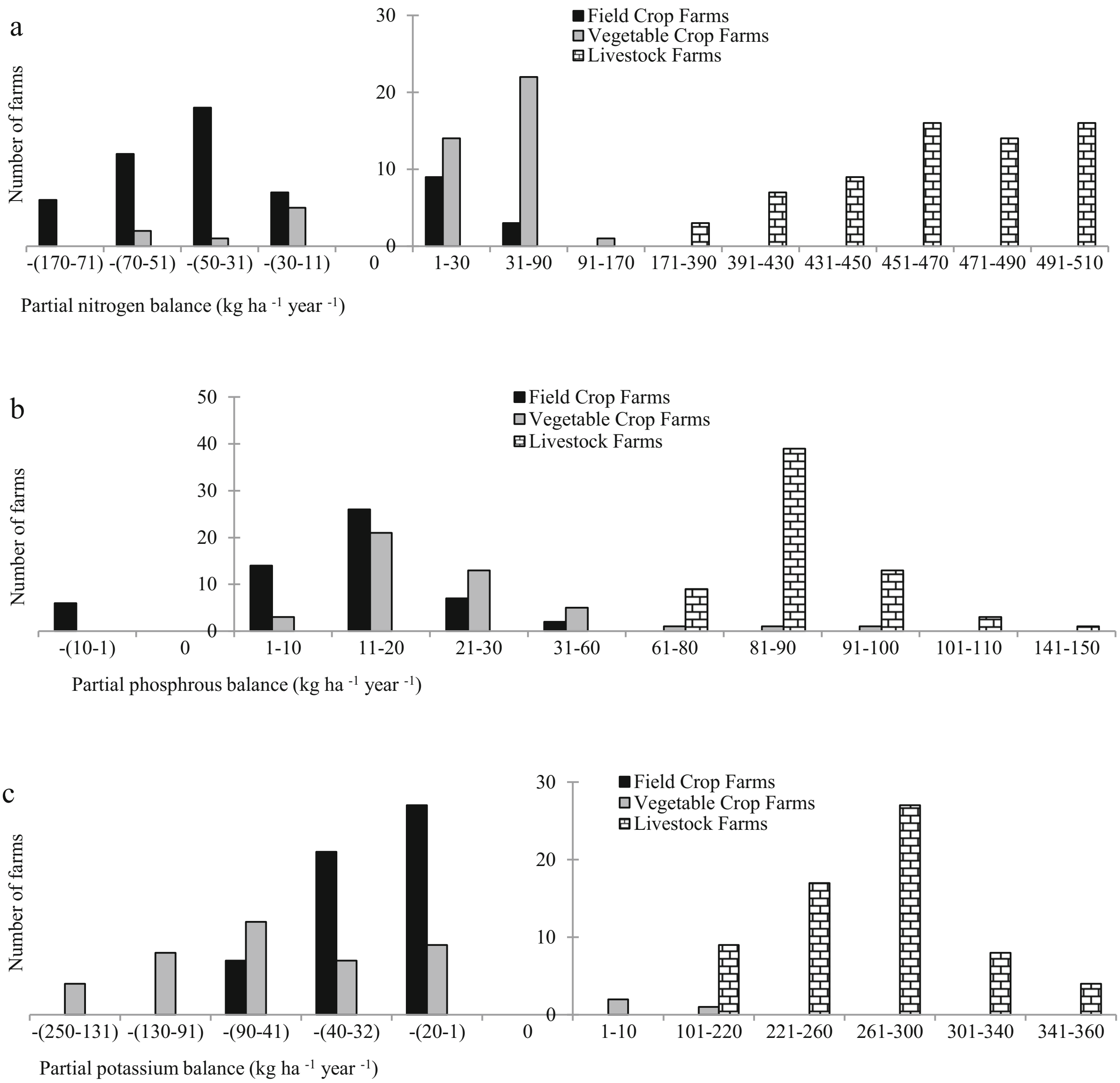

Fig. 5 Frequency distribution of partial **a** (nitrogen), **b** (phosphorus) and **c** (potassium) balances for the different farm types at Jimma city

Implications for intensification and improving NUE

Partial N, P and K balances were significantly different between the farm types per city (Table 6). Abdulkadir et al. (2013) also reported positive NPK balances for LS farms in the UPA systems of Kano in Nigeria from their partial nutrien balance analysis fairly comparable to ours. Their method of input and ouput quantification was monitoring. Our estimations were based on surveys in short recall time of the farmers, immediately following the seasons of agricultural activities. cVC farms had positive N and P balances but negative K balances. sFC farms had negative N and K balances but positive P balance. The positive N and P balances were related to the availability of NP fertilizers (DAP) on the market, which were affordable to cVC farmers but only marginally to sFC farmers. Potassium fertilizers were not available to farmers and hence negative K balances for the sFC and cVC farms. Nigussie et al.

Table 7 Summary of Multiple Regression Analyses of the relationships between socioeconomic variables and partial N and P balances (kg ha^{-1} $year^{-1}$) of UPA systems in Addis Ababa (N = 175), Adama (N = 126) and Jimma (N = 124)

Variables	Addis Ababa		Adama		Jimma	
	N balance β	P balance β	N balance β	P balance β	N balance β	P balance β
Family size	.25**	.2*	.03	.01	− .05	− .04**
HH[a] AGE	.27**	.12	.15	.18	.38**	.32
HH EDU	.14	.11	.01	− .01	.17*	.12
UPA EXP	− .10	.01	− .4**	− .4**	− .3**	− .28**
HH INC	.24**	.2*	− .13	− .16	.33**	.39**
R^2	.28	.10	.13	.10	.33	.33
F	10.48**	3.83**	3.62**	2.79**	11.46**	11.5**

* Denotes significant difference at $P < 0.05$

** Denotes significant difference at $P < 0.01$

[a] *HH* household head; β = Beta

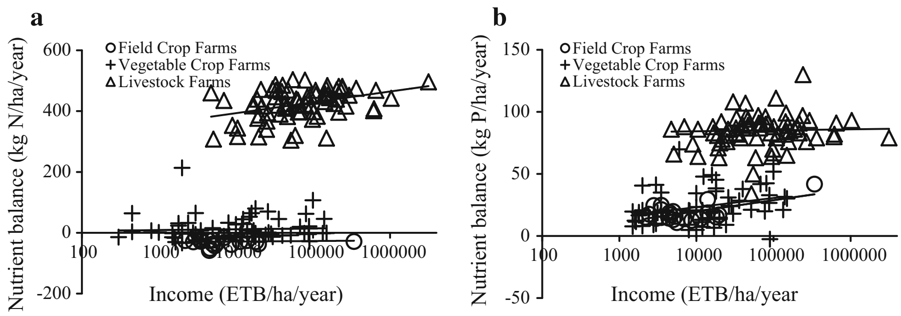

Fig. 6 The relation between income and balances of **a** nitrogen and **b** phosphorus for field crop, vegetable crop and livestock farms at Addis Ababa city. Solid lines show linear regression

(2015) also found positive N and P balances in cVC farms but a negative N balance in sFC farms. Another reason for the negative N balance in sFC farms is the use of crop residues for feed and fuel. Valbuena et al. (2015) also reported strong competition on crop residues for feed, fuel and soil amendment even under low levels of cereal production systems in SSA and South Asian countries. Regression analysis showed strong association of farm income and nutrient balances across the cities, income was positively related to N and P balances. Age of the household head was positively but UPA experience of the head was negatively related to N and P balances; these correlations are not easy to explain. The relation between farm income and N and P balance was stronger for cLS farms than cVC and sFC farms across the three cities (Fig. 6). The negative N balance in sFC farms were related to both the low income of these farms (Table 5) and to the relatively high price of fertilizers (Kassie et al. 2009). Abdulkadir et al. (2013) also found positive correlations between income and NP inputs in cLS farms. The high income of cLS farms was at the expense of nutrient accumulation in the urban environment (Table 6). In contrast, sFC and sVC farms generated low income and had negative nutrient balances, because crop residue and animal manure were used for feed and fuel, while inorganic fertilizers were little used.

Abdulkadir et al. (2013), Diogo et al. (2010) and Wang et al. (2008) reported positive N balances for various UPA systems. The difference in the N balances of UPA systems between our study and these three other studies under relatively similar production systems could be due to the differences in farm types, the level of farm intensification, and livelihood assets and strategies. Therefore, farm-specific nutrient balance analyses are required, since farmers with similar production systems could have different soil fertility management strategies. The K balance was negative for both VC and FC farms since they have been using DAP and urea as the only inorganic fertilizers available on the market. In agreement with this, different researchers (Abdulkadir et al. 2013; Diogo et al. 2010; Wang et al. 2008) also found negative K balances in urban and peri-urban farming systems. These negative nutrient balances in our study indicate soil fertility depletion. Firdisa et al. (2007) also found declining soil fertility in FC systems. Van Beek et al. (2016) reported soil fertility decline in Ethiopian highlands. The results of our study suggest that the soil fertility decline in FC in UPA systems across the three cities is relatively similar to that of the small holder farmers in Ethiopian highlands. Following the differences in the nutrient balances, the nutrient use efficency (NUE) of the farms also differed greatly. The sFC had the highest NUE (N, P and K) and the cLS farms had the lowest (Table 6). The high NUE of the sFC farms indicate low nutrient input relative to nutrient output with the harvested crops. In contrast, the low NUE of the cLS farms indicate these farms had low nutrient output relative to nutrient input via animal feed, while the animal manure was not used for crop or feed production, due to shortage of land. Ideally, the animal maures of cLS farms were transported to FC and VC farms, where there is high demand of biomass. This would improve the nutrient balances of both LS farms (surpluses will decrease) and VC and FC farms (soil mining may be reversed). Thus, linking the specialized systems, FC and VC farms with high demand of organic ammendment and LS farms with surplus manure will increase the amount of manure utilized on farmlands and at the same time decrease the burden of the manure discharges into the environment. Njenga et al. (2010) and Nigussie et al. (2015) also recommend urban waste compost in FC and VC farms to enhance the agronomic and environmental sustainability of UPA. The linkage of FC and LS systems can improve the NUE of the systems. Lassaletta et al. (2014) suggested that integration of FC and LS farming systems can increase the NUE of the systems.

Farm characteristics and socioeconomic conditions hinder sustainable intensification of agricultural production (Baudron et al. 2014). We found that high cost of inputs for crop production and high cost of feed for livestock production were the major constraints of UPA across the three Ethiopian cities, in agreement with the findings of Kassie et al. (2009) and Dercon and Christiaensen (2011). Therefore, improving the access of FC and VC farmers to inorganic fertilizers, and of LS farmers to feeds must have a high priority. This may be achieved through better linkages between the different farming systems. Governmental policies aimed at sustainable intensification of UPA should therefore focus on the exchange of manure and feeds between LS, VC and FC farms. Organic waste from urban households could possibly also play a role.

Conclusions

This study provides insights in the farm types, socioeconomic conditions and nutrient balances and constraints of UPA systems across three main cities in Ethiopia. Accordingly:

- Six distinct UPA farm types with different resource endowments, level of household income and constraints were identified.
- Among these, cLS production was the most important economic activity, followed by farm types integrating LS, VC and FC producton. sFC farming was mainly done by resource poor farmers for own consumption.
- The land-less cLS farmers didn't use the manure for soil fertility management, because of lack of land. The manure was also not collected by other farmers; instead the manure nutrients accumulated in the farmstead and/or neglected and dissipated into the wider environment. These farms had positive N, P and K balances.
- sFC farmers used crop residue mainly for fuel and not for soil fertility management. These farms had negative N, P and K balances.
- High costs of feed for LS farms and high cost of inputs for FC and VC farms were the most important constraints for further development of UPA in the cities.

Therefore, improving access of farmers to agricultural inputs and putting in place a policy linking the farm systems can stimulate sustainable intensification of UPA. But still, the farm types greatly differed in nutrient management, nutrient balances and losses. Mechanistic and comprehensive analysis of nutrient flows and balances is required for better understanding and further improvement of the farm systems productive and environmental performances.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Data availability All data generated or analyzed during this study are included in this published article and its supplementary information file.

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