Random and systematic land-cover transitions in north-eastern Wollega, Ethiopia

Alemayehu ADUGNA[1]
Assefa ABEGAZ[2]
Asmamaw LEGASS[2]
Diogenes L. ANTILLE[3]

[1] Wolaita Sodo University
Department of Geography
and Environmental Studies
Wolaita Sodo
Ethiopia

[2] Addis Ababa University
Department of Geography
and Environmental Studies
Addis Ababa
Ethiopia

[3] University of Southern Queensland
National Centre for Engineering
in Agriculture
Toowoomba, QLD
Australia.

Photo 1.
Deforestation in Northeastern Wollega, Ethiopia.
Photo A. Adugna.

Auteur correspondant / Corresponding author:
Alemayehu Adugna - alemadug@gmail.com

A. Adugna, A. Abegaz, A. Legass,
D. L. Antille

RÉSUMÉ

TRANSITIONS ALÉATOIRES ET SYSTÉMATIQUES DANS L'UTILISATION ET LA COUVERTURE DES TERRES DANS LE NORD-EST DU WOLLEGA EN ÉTHIOPIE

Des changements importants dans l'utilisation et la couverture des terres se produisent en Afrique à différentes échelles. Ces changements comprennent la déforestation suivie de la mise en culture des terres, de leur conversion en prairies ou leur urbanisation. Le présent article rend compte des travaux entrepris pour analyser les changements d'utilisation des terres dans le nord-est du Wollega (Éthiopie) entre 2005 et 2015. L'analyse a porté sur des transitions systématiques ou aléatoires, en identifiant les principaux facteurs de changement. Des données Landsat pour la période 2005 à 2015 ont été analysées pour mieux cerner les différentes dimensions des transitions : échanges, pertes, gains, persistance et vulnérabilité. Nos résultats indiquent les gains les plus importants pour les formations arbustives (22 %), avec un rapport gain/pertes de 63 %, un rapport gain/persistance de 47 % et un rapport net positif de 46 % pour le facteur changement/persistance. Les terres agricoles reculent le plus (19 %) alors que les prairies restent le type de végétation le plus stable, malgré quelques fluctuations (≈ 10 %) observées pendant la décennie étudiée. La transition est dominée par des processus systématiques, avec peu de processus aléatoires. Les transitions systématiques comme la déprise agricole ou la repousse forestière sont attribuées à des processus d'évolution réguliers ou communs. Cette étude indique que la mise en place de pratiques aptes à favoriser une intensification durable de l'agriculture existante, avec l'appui de politiques de diversification de l'agriculture éthiopienne, permettrait de réduire la pression sur les forêts en évitant leur conversion future en terres agricoles.

Mots-clés : déprise agricole, déforestation, repousse forestière, sécurité foncière, intensification durable, Ethiopie.

ABSTRACT

RANDOM AND SYSTEMATIC LAND-COVER TRANSITIONS IN NORTH-EASTERN WOLLEGA, ETHIOPIA

Africa has seen significant changes in land cover at different spatial scales. Changes in Land Use and Land Cover (LULC) include deforestation and subsequent use of the land for arable cropping, conversion to grassland or urbanization. The work reported in this article was conducted to examine land cover transitions in north-eastern Wollega (Ethiopia) between 2005 and 2015. The analysis focused on land cover transitions that occurred systematically or randomly, and identified the main drivers for these changes. Landsat data from 2005 and 2015 were examined to better understand the various dimensions of land cover transitions, namely: swaps, losses, gains, persistency and vulnerability. Results showed that shrubland exhibited the largest gain (22%), with a 63% gain-to-loss ratio, a 47% gain-to-persistence ratio and a positive net change-to-persistence ratio of 46%. Cropland showed the largest loss (19%) while grassland was the most stable type of land cover despite some fluctuation (≈10%) observed during the 10-year period. The land cover transition was dominated by systematic processes, with few random processes of change. Systematic land cover transitions such as agricultural abandonment and vegetation re-growth were attributed to regular or common processes of change. This study suggests that the implementation of practices conducive to sustainable intensification of existing agricultural land, supported by policies that promote increased diversification of Ethiopian agriculture, would mitigate pressure on forests by avoiding their future conversion to cropland.

Keywords: cropland abandonment, deforestation, forest re-growth, soil security, sustainable intensification, Ethiopia.

RESUMEN

TRANSICIONES ALEATORIAS Y SISTEMÁTICAS EN LA COBERTURA DE LA TIERRA EN EL NORESTE DE WOLLEGA EN ETIOPÍA

África ha experimentado importantes cambios en el uso y la cobertura de la tierra en diferentes escalas espaciales. Dichos cambios incluyen la deforestación seguida del cultivo de las tierras, la conversión en pastizales o su urbanización. Este artículo da cuenta de las investigaciones realizadas para analizar los cambios de uso de la tierra en el noreste de Wollega (Etiopía) entre 2005 y 2015. El análisis se centró en las transiciones sistemáticas o aleatorias e identificó los principales factores de cambio. Se analizaron los datos de Landsat del período 2005 - 2015 para comprender mejor las diferentes dimensiones de las transiciones: intercambios, pérdidas, ganancias, persistencia y vulnerabilidad. Nuestros resultados arrojan la mayor ganancia para el matorral (22%), con una relación ganancia/pérdida del 63%, una relación ganancia/persistencia del 47% y una relación positiva neta del 46% para el factor cambio/persistencia. Las tierras de cultivo muestran el mayor retroceso (19%), mientras que los pastizales son el tipo de cobertura más estable, a pesar de algunas fluctuaciones (≈10%) observadas durante la década estudiada. La transición está dominada por procesos sistemáticos, con escasos procesos aleatorios. Las transiciones sistemáticas como el abandono de tierras agrícolas o la regeneración forestal se atribuyen a procesos de evolución regulares o comunes. Este estudio sugiere que el establecimiento de prácticas conducentes a una intensificación sostenible de la agricultura existente, con el apoyo de políticas que favorezcan la diversificación de la agricultura etíope, reduciría la presión sobre los bosques evitando su futura conversión en tierras agrícolas.

Palabras clave: abandono de tierras agrícolas, deforestación, regeneración forestal, seguridad del suelo, intensificación sostenible, Etiopía.

Introduction

Studies using remote sensing technology have shown that land-cover changes are mainly due to deforestation, expansion of cropland areas, including areas used for pastures, urbanization, and increased desertification (Carmona and Nahuelhual, 2012; Belay *et al.,* 2015). Such changes in land-cover are more significant in tropical regions compared with areas outside the tropics (Lambin *et al.,* 2003). For example, the rate of deforestation in tropical countries was estimated to be approximately 7 million hectares per year on average between 2000 and 2010 while the rate of forest re-growth was estimated at about 1 million hectares per year over the same period (FAO, 2015). By contrast, the area used for cropping in tropical regions exhibited a gain of approximately 6 million hectares per year during the 10-year period indicated above. Globally, the expansion of agricultural land has mainly occurred at the expense of forests and natural areas of non-agricultural use, which have shrunk by approximately 16% and 5%, respectively (Brink and Eva, 2009). Underlying factors affecting conversion of forest into cropped land are: population growth, socio-economic changes, active policy intervention or lack of appropriate policy measures aimed at protecting the natural environment, and technology changes (Lambin *et al.,* 2003).

Recent studies conducted in Ethiopia (e.g., Messay, 2011) showed that the main land-covers are: woodland (27%), shrubland (21%), cropping (19%), grassland (12%), natural forest (4%), and other land uses (17%), which includes urban and industrial areas, mining areas, and mountains. Land-cover changes such as expansion of subsistence crop production into the ecologically-fragile environments of the Ethiopian highlands and deforestation have been significant over the past few decades (Kassa *et al.,* 2011). These changes in land-cover have contributed to increased soil erosion rates and reduced land productivity, and are mentioned to have adverse effects on climate change (Bewket and Teferi, 2009; Nyssen *et al.,* 2015). In eastern Ethiopia, Mohammed (2013) also showed that the area of cultivated land expanded as a result of deforestation, which has resulted in increased erosion in the catchment of Lake Alemaya. Demeke (2013) quantified and mapped the extent and spatial patterns of land-cover over a 30-year period in the Borodo watershed in central Ethiopia, and showed that open lands expanded because of progressive removal of shrubs and forest. Further work by Yodit and Fekadu (2014) examined land-cover changes in the Kebribeyah district of the Somali Region of Ethiopia and reported greater settlement areas due to population growth. Other drivers of land-cover changes identified by Yodit and Fekadu (2014) were: price incentives, intervention by development agencies, change in land tenure and development of urban infrastructure, attitudinal change of pastoralists, and deforestation. Similar observations in terms of land-cover dynamics were also reported by Amanuel and Mulugeta (2014) for the Nada Asendabo region in south-western Ethiopia. A requirement for further work has been identified to determine dominant land-cover changes, when and where, and at what rate these changes take place. Therefore, this study investigated land-cover changes observed in north-eastern Wollega and discussed processes of land-cover transition associated with those changes.

Accurate information on processes driving land-cover changes may be obtained through the detection of dominant land-cover transitions (Pontius *et al.,* 2004; Braimoh, 2006). Land-cover transitions can be classified as random or systematic based on the rate of change (Pontius *et al.,* 2004; Braimoh, 2006). Abrupt or unique processes of change in land-cover are regarded as random (Carmona and Nahuelhual, 2012). Random land-cover changes are caused by unexpected factors such as spontaneous migration, conflicts, insecure land tenure, changes in socio-economic conditions, as well as factors influencing agricultural production (Lambin *et al.,* 2003). Systematic transitions are characterized by permanent, stable or common processes of change. Population growth, large-scale commercial agriculture and subsistence agriculture, lack of public awareness on environmental management-related issues, and changes in functions of institutions that control the right to use natural resources are often regarded as the main factors driving systematic transitions (Siren, 2007). North-eastern Wollega (Ethiopia) has a relatively rich natural environment in terms of its diversity, and has experienced significant changes in land-cover (Urgesa *et al.,* 2016). For the area relevant to our study, there appears to be a knowledge gap in identifying systematic transitions and understanding the determinants for such transitions. Therefore, the objectives of this study were to: (i) identify systematic and random transitions and their determinants, and (ii) explore the implications of those transitions for land management and food security in Northeastern Wollega, Ethiopia.

Materials and methods

Study area

The study area (figure 1) is located in north-eastern Wollega and within the Horo-Guduru Wollega region (Ethiopia), which covers an area of 14,979 ha that extends from 9°45' N to 10°00' N, and from 37°00' E to 37°15' E, respectively. The mean annual temperature is 27°C and the mean annual rainfall is approximately 1,900 mm. North-eastern Wollega is the source of the Hangar River, which is the main tributary of Nile River (locally known as Abay). Dominant tree species include *Juniperus* sp. (Tid), *Podocarpus* sp. (Zigba), *Olea europaea* (Woyera), *Rosa abyssinica* (Kega) and *Carissa edulis* (Agam). Nitosols are the dominant soil type on undulating ground and steep slopes (Adugna and Abegaz, 2016). Relatively flat river valleys have well-developed Vertisols, whereas Regosols and Cambisols are also found on steep slopes areas. The area has a population of ≈59,000, which has increased at an average rate of ≈3% per year. Agriculture is the primary form of occupation for about 90% of the population, and includes both cropping and livestock farming. The main crops are cereals, which are produced for subsistence. Livestock is usually tethered and uses the "cut and carry" feeding system. Cut and carry, also known as zero-grazing, is a feeding system consisting of cutting, collecting and transporting the forage to the cattle, which is maintained indoor. Horse-carts are used for carrying the harvested forages from the field. This system is commonly practiced by smallholder farmers.

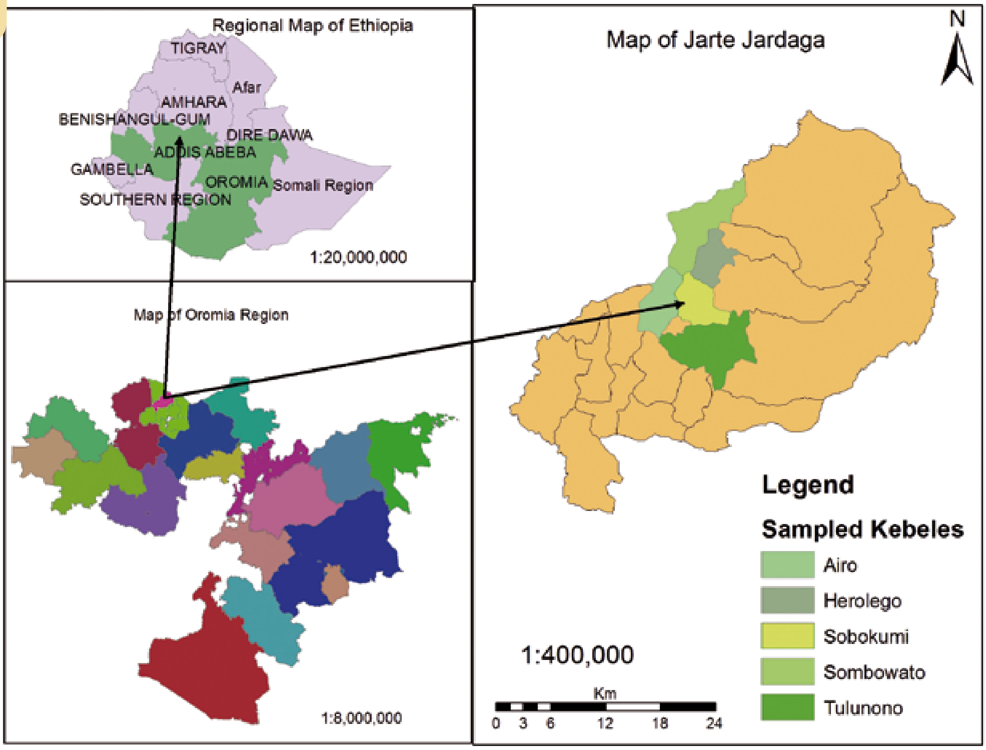

Figure 1.
Map of the study area (Jarte Jardaga) in north-eastern Wollega, Ethiopia.

Data source and land-cover sampling

Landsat images from 2005 and 2015 were used to identify land-cover transitions. The Enhanced Thematic Mapper-Plus from Landsat 5 (February 2005 and February 2015, path 168, row 55) was the source of data. February was selected because it is the driest month in Ethiopia when the sky is free from clouds obstruction and sensors are able to capture untainted surface reflectance. Using Band 3 (visible 0.63-0.69 µm) and Band 4 (near-infrared 0.75-0.90 µm), the images were radiometrically corrected based on sensors' calibration parameters provided by the satellite images and Equation 1 (Awdenegest and Holden, 2009):

$$L = \frac{L_{max} - L_{min}}{255} \times DN + L_{min} \quad (1)$$

where: L is the radiance ($Wm^{-2}\ sr^{-2}$), and DN is the digital number, subsequently used to calculate the NDVI, as follows (Equation 2):

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (2)$$

Where *NDVI* is the Normalized Difference Vegetation Index, NIR is the spectral reflectance measurements acquired in the Near Infrared channel, and R is s the spectral reflectance measurements acquired in the red channel.

NDVI data were analysed to define cover classes. Generally, NDVI ranges from -1 to 1, where higher values reflect higher vegetation cover and lower values represent shrubland, grassland, cropland and settlement. Landsat Enhanced Thematic Mapper (ETM+)-derived NDVI data were categorized into 5 land-cover classes listed above based on the values from the literature (e.g., Smith *et al.*, 2007) and field observations. Land-cover classification was performed using the supervised maximum likelihood algorithm classifier to allocate pixels to land-cover classes (Oudraogo *et al.*, 2015). After the land-covers were classified, changes were calculated and maps were prepared. ArcMap geographic information system was used for analysis and preparation of the maps.

The two maps (2005 and 2015 Landsat images) were geometrically rectified into the Universal Transverse Mercator-World Geodetic System (UTM-WGS 84 Zone 37) ahead of change detection. This was performed using topographic maps and digital elevation models derived from Landsat images. A tasselled cap orthogonal transformation of the original bands was performed to improve the visual classification of land-cover types. This process required a thorough ground truthing, which was conducted in 2015 to include collection of ground control points, training areas, ground-check and validation. The number of samples (*n*) for training areas and the validation for each of the land-cover classes was selected by applying Equation (3) from the multinomial distribution (Congalton and Green, 1999), as follows:

$$n = \frac{B\pi_i(1 - \pi_i)}{b_i^2} \quad (3)$$

where: B=6.63 is the upper $\left(\frac{\alpha}{k}\right) \times 100^{th}$ percentile of the x^2 distribution with one degree of freedom, π denotes a 0.01 level of significance, and π_i (i = l…,k)is the proportion of the population in the i^{th} category, b is the absolute precision of the sample, k is number of land-cover categories. Equation (3) is calculated for each of '*k*' categories and '*n*' for all categories is subsequently selected proportional to the size of the category. The analysis used a 95% confidence level, which is considered to be appropriate based on related studies, and the absolute precision was set at 0.05. For the

Table I.
Land-cover, sample size, producer's accuracy and user's accuracy assessment in North-eastern Wollega, Ethiopia.

No.	LULC	Sample size (n=)	Producer's accuracy (%)	User's accuracy (%)
1	Forestland	483	79.4	71.1
2	Shrubland	50*	71.4	68.2
3	Grassland	239	70.2	73.9
4	Cropland	620	76.6	84.1
5	Settlement	70	86.0	84.2

Note: For shrubland, 50 sample sizes were chosen as the desired sample size close to Congalton and Green (1999)'s rule-of-thumb of a minimum of 50 samples per class since the value was small to consider for the study using Equation (1). LULC is land-use/land-cover.

Table II.
A 5×5 land-cover matrix.

2005 LULC	Forestland	Shrubland	Grassland	2015 Cropland	Settlement	Total 2005	Loss
Forestland	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{1+}	C_{1+}-C_{11}
Shrubland	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{2+}	C_{2+}-C_{22}
Grassland	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{3+}	C_{3+}-C_{33}
Cropland	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{4+}	C_{4+}-C_{44}
Settlement	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}	C_{5+}	C_{5+}-C_{55}
Total (2015)	C_{+1}	C_{+2}	C_{+3}	C_{+4}	C_{+5}	1	-
Gain	C_{+1}-C_{11}	C_{+2}-C_{22}	C_{+3}-C_{33}	C_{+4}-C_{44}	C_{+5}-C_{55}	-	-

Note: "C" is any conversion from one land-cover to another. LULC is land-use/land-cover.

study site, '*n*' from the smallest class was chosen as the desired sample size to match Congalton and Green (1999)'s rule of thumb of a minimum of 50 samples. Stratified random sampling methods were used to collect an optimum number of sample reference polygons for the classification accuracy assessment. The population (sampling frame), land-cover classes, embraces distinct categories (separate strata): forestland, shrubland, grassland, cropland, and settlement, respectively. Each stratum is subsequently sampled as an independent sub-population from which individual elements can be randomly selected (table I). Producer's accuracy (measure of omission error) was computed by dividing the total number of correct pixels in a category by the total number of pixels of that category as derived from the reference data (the column total). This method illustrates how well a certain area can be classified or indicates the probability of a reference pixel being correctly classified. The user's accuracy, that is, a measure of commission error is computed by dividing the total number of correct pixels in a category by the total number of pixels that were classified in that category (the row total). This provides a measure of reliability and indicates the probability of a pixel classified on the map or image actually represents that category on the ground. The overall accuracy was 82% for 2005 and 86.7% for the 2015 land-cover maps.

The types of land-cover within the study area were classified into five categories, based on previous work by Lambin *et al.* (2003). These categories were: (1) forestland (high and dense trees with 70%-100% closed canopy), (2) shrubland (bush canopy mixed with some trees, closure areas, young forest plantations and agroforestry), (3) grassland (mainly grasses without long-fallowed land or with less than 10 trees per ha), (4) cropland (agricultural land with crops as well as harvested agricultural land), and (5) settlement (built-up areas).

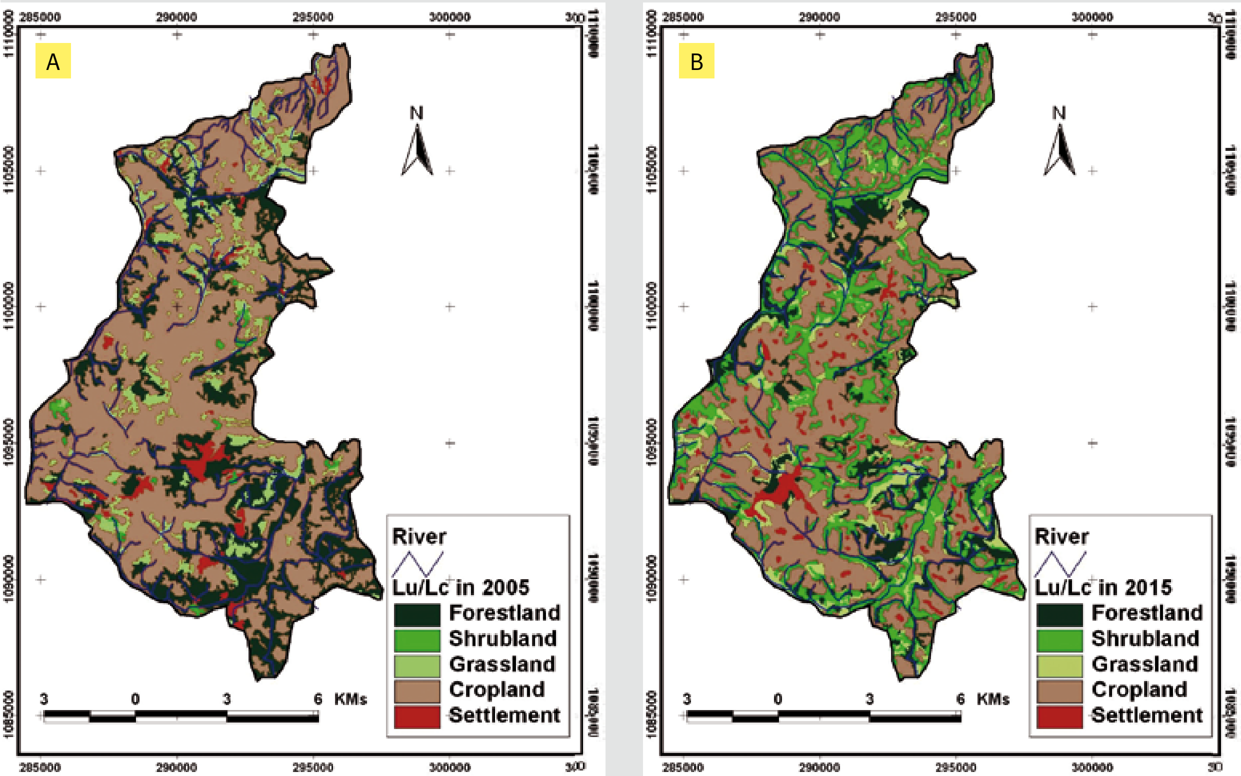

Figure 2.
Map of land-cover change in 2005 (A) and 2015 (B) in north-eastern Wollega, Ethiopia.

Data analysis

Land cover transition matrix

Land-cover transitions were analyzed using a transition matrix obtained from cross-tabulation of the two-raster maps presented in figure 2. The approach of Pontius *et al.* (2004) was used to identify major signals of systematic land cover changes. The general structure of the transition matrix was shown in such a way that the columns and rows presented the proportions of the five land-cover classes in 2005 and 2015, respectively (table II). The main diagonal elements (i.e., C_{jj}) designate the proportion of persistent land-cover classes that showed no changes. Diagonal elements were used to calculate the gains and the losses of land-cover classes (Pontius *et al.,* 2004). The off-diagonal elements showed the amount of the land-cover transformed from class *i* to class *j* between 2005 and 2015 as calculated using Equations (4a-b) (after Pontius *et al.,* 2004; Ouedraogo *et al.,* 2010).

$$C_{i+} = \sum_{i=1}^{n} C_{ij} \quad (4a)$$

$$C_{+j} = \sum_{i=1}^{n} C_{ij} \quad (4b)$$

where: *n* is the total number of classes, C_{ij} (where *i # j*) designates the proportion of the landscape that experienced a transition from class *i* to class *j* between 2005 and 2015, C_{i+} is the proportion of land-cover in 2005 and C_{+j} the proportion of land-cover in 2015.

The "loss" column indicates the amount of land-cover that experienced a net loss of class *i* between 2005 and 2015, whereas the "gain" rows show the amount of the land-cover that experienced a gross gain of class *j* between the same two years (table II). Swap is the exchange between classes, and denotes concurrent gain (i.e., difference between class *i* and persistence) and loss (i.e., difference between class *j* and persistence) of a given land-cover class. Equation (5) describes the proportions of swap, which required the pairing of each pixel that loses with those pixels that gain (Braimoh, 2006):

$$S_j = 2\ \min\ \left(C_{i+} - C_{ij}\right),\left(C_{+i} - C_{ij}\right) \quad (5)$$

where: S_j is amount of swap of land class *j*, 2 min is twice the minimum of the gain and loss, C_{i+} is the proportion of land-cover in 2005, C_{+j} the proportion of land-cover in 2015 and C_{ij} (where *i # j*) designates the proportion of the landscape that experienced a transition from class *i* to class *j* between 2005 and 2015, respectively.

Photo 2.
Land-cover transition in north-eastern Wollega, Ethiopia.
Photo A. Adugna.

Vulnerability of land-cover to transition

The vulnerability to transition of each land-cover class is calculated using the gain-to-persistence ratio ($G_p = \frac{g}{p}$), the loss-to-persistence ratio ($L_p = \frac{l}{p}$), and the net change-to-persistence ($N_p = G_p - L_p$), respectively (Ouedraogo *et al.*, 2010). The terms *g*, *p*, and *l* stand for gain, persistence (that is areas of a given category that remained unchanged), and loss, respectively. Values of G_p and L_p greater than one imply that a given land-cover class has a higher probability to change to other land-cover class than to persist in its current condition (Braimoh, 2006). If the value of N_p was negative, the land-cover class would have a higher probability to lose area to other land-cover classes than to gain from them.

Detection of systematic and random transitions

Land-cover data from 2005 and 2015 were used to analyze recent land-cover transition processes observed in north-eastern Wollega (Ethiopia). The procedure employed in our study is based on approaches satisfactorily applied in earlier studies (e.g., Pontius *et al.*, 2004; Braimoh, 2006; Ouedraogo *et al.*, 2010; Ouedraogo *et al.*, 2014; Ouedraogo *et al.*, 2015). Detection of systematic and random inter-category transitions involves four interrelated procedures. The first procedure calculates the expected gain (G_{ij}) for each class under a random process of gain (Equation 6), as follows (Pontius *et al.*, 2004):

$$G_{ij} = \left(C_{+j} - C_{jj}\right)\left(\frac{C_{i+}}{1 - C_{j+}}\right), \forall i \neq j \quad (6)$$

where: G_{ij} is expected gain of each cover type, C_{+j} is the proportion of land-cover in 2015, C_{jj} is the proportion of persistent land-cover classes that showed no changes and C_{i+} is the proportion of land cover in 2005. Equation (6) distributes the gain across the off-diagonal entries of 2015 according to the relative proportions of the other classes in 2005. The assumption of this equation is that the gain for each class and the proportion of each class in 2015 remain unchanged. These expected gains represent the random process of gain. The second procedure estimates the difference between the observed (measured) and expected proportions of gain under a random process of gain. Large positive or negative differences from zero denote systematic inter-category transitions, rather than random transitions, which occur between two land-cover classes. The larger the variance (positive), the larger the area affected by systematic gain of class *j* from class *i*, and the larger a negative calculated variance, the weaker the tendency of class *j* to gain systematically from class *i* (Braimoh, 2006; Ouedraogo *et al.*, 2014). The third procedure calculates the expected loss, L_{ji} (loss of class *i* to class *j*) under a random process of loss using Equation (7) (Braimoh, 2006):

$$L_{ij} = \left(C_{i+} - C_{jj}\right)\left(\frac{C_{i+j}}{1 - C_{+i}}\right), \forall i \neq j \quad (7)$$

where: L_{ij} is expected loss, C_{i+} is the proportion of land-cover in 2005, C_{jj} is proportion of persistent land-cover classes that showed no changes and C_{+j} is the proportion of land-cover in 2015.

Equation (7) assumes that the loss of each land-cover class is fixed and the loss in each row across the other classes is distributed relative to their proportions in 2015. The forth

Table III.
Land-cover changes (%) observed in north-eastern Wollega, Ethiopia.

LULC	Total 2005	Total 2015	Persistence	Gain	Loss	Total change	Swap	Net change (absolute value)
Forestland	23.9	11.2	7.8	3.4	16.2	19.6	6.8	12.8
Shrubland	0.8	22.5	0.5	22.0	0.4	22.4	0.7	21.7
Grassland	9.9	8.3	1.1	7.3	8.9	16.1	14.5	1.6
Cropland	62.6	55.2	43.4	11.8	19.2	31.0	23.5	7.4
Settlement	2.7	2.8	0.3	2.5	2.4	4.9	4.8	0.1
Total 2015	100.0	100.0	53.0	47.0	47.0	93.9	50.3	43.6

Table IV.
Land-cover change matrix (%) between 2005 and 2015 for north-eastern Wollega, Ethiopia.

2005			2015				
LULC	Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
Forestland	7.8	9.4	1.8	4.9	0.1	23.9	16.2
Shrubland	0.1	0.5	0.1	0.2	0.0	0.8	0.4
Grassland	0.7	2.8	1.1	5.1	0.2	9.9	8.9
Cropland	2.4	9.4	5.2	43.4	2.2	62.6	19.2
Settlement	0.2	0.4	0.2	1.6	0.3	2.7	2.4
Total 2015	11.2	22.5	8.3	55.2	2.8	100.0	47.0
Gain	3.4	22.0	7.3	11.8	2.5	47.0	-

Table V.
Gain-to-persistence (G_p), Loss-to-persistence (L_p), and net change-to-persistence (N_p) ratio of the land cover classes in the north-eastern Wollega, Ethiopia

	Gain (g)	Loss (l)	Persistent (P)	G_p	L_p	N_p
Forestland	3.4	16.2	7.8	0.4	2.1	-1.6
Shrubland	22.0	0.4	0.5	46.9	0.7	46.1
Grassland	7.3	8.9	1.1	6.8	8.3	-1.5
Cropland	11.8	19.2	43.4	0.3	0.4	-0.2
Settlement	2.5	2.4	0.3	1.1	8.3	-7.2

procedure calculates the difference between the observed and expected proportions of gain under a random process of loss. Likewise, large positive or negative differences from zero indicate that systematic inter-category transitions, rather than random transitions, have occurred between two land-cover classes. The larger a positive calculated variance, the higher the area affected by systematic loss of class *i* to class *j*, and the larger a negative calculated variance, the weaker the tendency of class *i* to systematically loss to class *j* (Braimoh, 2006; Ouedraogo *et al.*, 2014). Generally, it can be concluded that the transition from class *i* to class *j* is a systematic process if class *i* loses systematically to class *j*, and class *j* gains systematically from class *i* (Pontius *et al.*, 2004).

Results

Land-cover transitions

In north-eastern Wollega, land-cover exhibited significant changes during the 10-year period investigated in this study, as shown in table III and figure 2. In 2005 and 2015, forestland accounted for ≈24% and ≈11% of the total area, respectively. The area of cropland decreased from ≈63% in 2005 to ≈55% in 2015 while grassland areas remained close to constant during the same period (table III). Shrubland areas increased from less than 1% to 22.5% between 2005 and 2015, respectively. The loss in area of cropland was highest representing almost 20% of the landscape. The gain-to-loss ratio was highest (55.0) for shrubland and settlement (1.0), and lowest for forestland (0.2) and cropland (0.6), respectively. Changes attributable to location (swap) were highest for cropland (23.5% of the change in cropland), followed by grassland (14.5% of the change in grassland) and forestland (6.8% of the change in forestland), respectively. Net changes (quantity) were highest for shrubland (≈22%) and forestland (≈13%).

Persistence and vulnerability of land-cover

The proportion of different land-cover classes that remained unchanged (persistence) from 2005 to 2015 is presented in table III. The land used for cropping showed relatively less changes compared to settlement areas (table IV). Among the natural vegetation, forestland and shrubland areas exhibited the highest and lowest persistence, respectively (table III). The vulnerability of land-cover classes to transition exhibited some variability depending on the type of land-cover, as shown in table V. The gain-to-persistence ratio (G_p) was higher than one in all land-cover classes with the exception of forestland and cropland (table V). The G_p ratio was highest for shrubland (46.9) and lowest for cropland (0.3). The loss-to-persistence ratio (L_p) for all land-covers, except for cropland and shrubland, was higher than one (table V). The L_p ratio was highest for grassland (8.3) and lowest for cropland (0.4). The net change-to-persistence (N_p) was positive for shrubland and negative for the other land-cover classes (table V). The N_p value was highest for shrubland (46.1), followed by settlement (-7.2). By contrast, the value of N_p was lowest (-0.2) for cropland.

Systematic and random processes of change in north-eastern Wollega

The expected gains for each land-cover class under random process of gain are shown in table VIa, and the difference between observed and expected gains in table VIb. Differences between observed and expected gains for cropland-forestland and forestland-cropland transitions were 0.3% and 2.1%, respectively. This indicated that forestland randomly gained 2.4% of the landscape from cropland, whereas cropland systematically gained 4.9% of the landscape from forestland (table IV). Differences between observed and expected gains for forestland-shrubland and cropland-shrubland transitions were 4.1% and -4.4%, respectively (table VIb). Therefore, this suggested that there was a systematic exchange of forestland and cropland with shrubland. Shrubland gained systematically 9.4% of the landscape from forestland and cropland (table IV). The difference between observed and expected gain for cropland-grassland and grassland-cropland transitions were 0.7% and 3.9%, respectively. This suggested that during the 10-year period there was a systematic exchange between cropland and grassland. Grassland systematically gained 5.2% of landscape from cropland, whereas cropland systematically gained 5.1% of the landscape from grassland. Differences between observed and expected gains for forestland-settlement and cropland-settlement transitions were -0.5% and 0.6%, respectively. This indicated that settlement systematically gained 0.1% and 2.2% of the landscape from forestland and cropland, respectively (table IV).

Expected losses under a random process of loss are given in table VIIa, and the difference between the observed and expected losses in table VIIb. Relatively large differences between observed and expected loss for forestland to shrubland (9.3%) indicated that forestland systematically lost to shrubland. Large negative values of cropland to forestland transitions (-6.5%) imply that loses of cropland to forestland areas were systematically avoided. Large differences between observed and expected loss for cropland to shrubland (9.2%), cropland to grassland (4.5%) and cropland to settlement (0.8%) transitions indicate that cropland tended to lose systematically to other land-cover classes.

Discussion

Results showed that shrubland represented the least dominant form of land-cover in 2005, but this condition was reverted by 2015. The calculated gain-to-loss ratio for shrubland suggested that this type of land-cover exhibited 63 times more gain than loss, and that it will likely continue to increase. The assessment of vulnerability of land-cover to transition also showed a high *Gp* value for shrubland (47), implying that this land-cover is prone to gain area from other types of land-cover than it is to persist. This relates to conversion of forestland to shrubland, afforestation of land previously not occupied by forest, improvement of shrubland in protected areas, and agricultural abandonment with subsequent expansion of natural forest into areas previously under arable cropping. These processes combined are understood to have assisted the rehabilitation of degraded land in NE Wollega, also noted in earlier studies in NW Ethiopia (e.g., Bewket, 2007). The implementation of the 1997 Environmental Policy of Ethiopia (EPE, 1997) may also explain changes (increase) in the area occupied by shrubs. EPE encourages tree planting including forestry development on farms, around homesteads, and on eroded hillsides. It has also introduced a ban on illegal hunting, bushfire and free mobility of livestock so as to improve secondary forest cover in protected areas. This policy instrument assists adoption of best management practice for natural forests and woodland resources, and encourages sustainable and participatory approaches to natural resource management (Teshome *et al.*, 2014).

Table VI.
Inter-category gains in north-eastern Wollega, Ethiopia: (a) expected gain, and (b) difference between observed and expected.

2005 LULC	2015 Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
	(a) Expected gain under a random process of gain (%)						
Forestland	7.8	5.3	1.7	2.8	0.6	18.2	10.4
Shrubland	0.1	0.5	0.1	0.1	0.1	0.7	0.2
Grassland	0.3	2.2	1.1	1.2	0.3	5.0	4.0
Cropland	2.1	13.8	4.5	43.4	1.6	65.5	22.1
Settlement	0.1	0.6	0.2	0.3	0.3	1.5	1.2
Total 2015	10.4	22.3	7.6	47.8	2.7	90.9	37.8
Gain	2.6	21.9	6.5	4.4	2.5	37.8	-
LULC	**(b) Difference between the observed land-cover transitions and the expected gain (%)**						
Forestland	0.0	4.1	0.1	2.1	-0.5	5.7	5.7
Shrubland	0.1	0.0	0.0	0.1	-0.1	0.1	0.1
Grassland	0.4	0.7	0.0	3.9	-0.1	4.9	4.9
Cropland	0.3	-4.4	0.7	0.0	0.6	-2.9	-2.9
Settlement	0.1	-0.2	-0.1	1.3	0.0	1.2	1.2
Total 2015	0.8	0.2	0.7	7.4	0.1	9.2	9.2
Gain	0.8	0.2	0.7	7.4	0.1	-	-

Table VII.
Inter-category losses in north-eastern Wollega, Ethiopia: (a) expected loss, and (b) difference between observed and expected loss.

2005 LULC	2015 Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
	(a) Expected loss under a random process of loss (%)						
Forestland	7.8	0.1	1.0	2.1	0.3	11.2	3.4
Shrubland	3.6	0.5	2.0	4.3	0.5	11.0	10.5
Grassland	1.3	0.1	1.1	1.6	0.2	4.3	3.2
Cropland	8.9	0.2	0.7	43.4	1.3	54.6	11.2
Settlement	0.5	0.1	0.3	0.5	0.3	1.5	1.3
Total 2015	22.1	0.7	5.0	52.1	2.6	82.6	29.5
Gain	14.4	0.3	4.0	8.6	2.3	29.5	-
LULC	**(b) Difference between the observed landscape transitions and the expected loss (%)**						
Forestland	0.0	9.3	0.8	2.1	-0.5	11.7	11.7
Shrubland	-3.6	0.0	-1.9	0.1	-0.1	-5.4	-5.4
Grassland	-0.6	2.8	0.0	3.9	-0.1	6.1	6.1
Cropland	-6.5	9.2	4.5	0.0	0.6	7.8	7.8
Settlement	-0.3	0.4	-0.1	1.3	0.0	1.4	1.4
Total 2015	-11.0	21.8	3.3	7.4	0.1	21.5	21.5
Gain	-11.0	21.8	3.3	7.4	-0.1	21.4	-

Loss of forestland is mainly attributed to deforestation aimed at developing new agricultural land as well as logging for firewood and charcoal production (FAO, 2015). The assessment of land-cover transition process showed that forestlands are systematically transformed to croplands implying that farmers have preferentially cleared-up forests to make space for new farmland. Historically, Ethiopian farmers have increased agricultural output through this process, but with proportionally less increases in productivity per unit area (Ndah *et al.,* 2015). Large-scale forest conversion and expansion of livestock-based farming means that the amount of suitable land available for cropping is rather limited in north-eastern Wollega. Thus, as of 2015 cropland areas experienced a loss and tended to decrease during the past decade, but it is still the dominant land-cover in the region. This loss was mainly associated with the abandonment of cropland areas due to soil degradation in the form of erosion, also highlighted in studies in the Gerado catchment (e.g., Bahir *et al.,* 2015), the central Ethiopian Highlands (e.g., Adimassu *et al.,* 2013), and other tropical regions (e.g., Schneider and Geoghegan, 2006; Carmona and Nahuelhual, 2012; Angonese and Grau, 2014).

Cropland areas increased little (7.4%), which was also observed for grassland (1.6%) and settlement (0.1%) areas. A low *Gp* value (0.3) for cropland suggested that this class is prone to losing area to other land-cover types, and means that there were relatively large swaps resulting from concurrent gains and losses of similar order of magnitude (table III). As a result, there has been a relocation of 24% of the cropland area, which in turn reflects a process of agricultural adjustment. Agricultural adjustment is a process by which agricultural lands are relocated to relatively more fertile or productive areas (Carmona and Nahuelhual, 2012). This process plays a critical role in promoting re-establishment of native vegetation in degraded areas, but it requires some degree of resilience of that environment to enable basic ecosystem's functions to be progressively restored (Ouedraogo *et al.,* 2014). While this process has taken place in north-eastern Wollega, other factors are also noted. For example, spontaneous abandonment of agricultural production by farmers on degraded land is considered to be one of the main drivers behind deforestation reversal and subsequent forest re-growth (Singh *et al.,* 2015).

The findings of our study support the need of Ethiopian farmers to shift towards a process of sustainable intensification of agriculture to ensure long-term protection of the soil resource and advance food security in the region. These observations are in agreement with earlier studies (e.g., Alexandratos, 2005; Pretty *et al.,* 2011). The opportunities for opening-up of new land from forest, wetlands, hillsides or pastures for cultivation of arable crops are largely regarded as non-sustainable practices and therefore should be avoided. At present, no steps towards sustainable intensification of agriculture in the region have been taken. By contrast, the socio-economic context and the agricultural policies in place have traditionally pointed towards extensification (land-demanding strategy). Furthermore, sustainable intensification is perceived as risky by most farmers due to the level of investment required for the provision of means needed to improve productivity. Other limiting factors are also encountered such as inadequate resource allocation, restricted access to technology, lack of qualified labor and the land tenure system (Bahir *et al.*, 2015). Limited extension effort also means that farmers are largely unaware of alternatives practices available for mitigation of environmental degradation.

A study by Wood *et al.* (2004) suggested that the following is required to drive sustainable intensification of agriculture forward: agricultural products can be commercialized, input and output markets are accessible, return on investment is satisfactory, labor is available, and farmers have financial means to acquire agricultural inputs. Availability of labor in rural areas is reduced when migration from rural to urban areas is significant, and people formerly employed in the agricultural sector join non-farming related sectors (Pretty *et al.,* 2011). Agricultural abandonment has both positive and negative consequences on the environment and rural livelihood (Izquierdo *et al.,* 2009; Barbier *et al.,* 2010). Negative consequences include the disappearance of traditional farming practices, food shortages and associated poverty, and potential invasion of exotic species (Zucca *et al.,* 2015). Positive impacts are also reported and include restoration of ecosystem services and functions, but this requires some degree of intervention (Ouedraogo *et al.,* 2010; Ouedraogo *et al.,* 2014). In our study, agricultural abandonment was regarded as a process that involves steady conversion of the land previously used for agricultural production towards natural vegetation. Our results showed that the transition of landscapes from cropland to shrubland, grassland and settlement was mainly explained by a systematic rather than a random process of change. Based on this, it is possible to state that local farmers appear to preferentially fallow or abandon croplands to make space for pasture production and expansion of agroforestry. This also suggested that there appears to be a shift from cropping to other activities, such as cattle fattening, trade, and handicraft and service provisions.

Conclusions

The main conclusions derived from this work are:

The land-cover changes observed in this study denote a trend towards abandonment of agricultural land, which is likely to assist environmental restoration through natural processes. The land-cover classes investigated showed that shrubland areas had the highest gains whereas cropland areas exhibited the highest losses. Consequently, abandonment of croplands and re-growth of natural forest were identified as the main land-cover changes in north-eastern Wollega.

Land-cover changes in north-eastern Wollega have undergone systematic transitions. The main drivers for such transitions were abandonment of cropland areas and clearing-up of forests for arable cropping and grazing. Environmental policy in Ethiopia should aim at rehabilitating degraded land and restoring ecosystems' functions. The effectiveness of such measures needs to be assessed at time intervals appropriate for the land-use and climate.

Land-cover transitions in north-eastern Wollega had positive implications for land management and food security in the region. The rapid expansion of shrubland implies that there has been afforestation of land previously not occupied by forest. Afforestation assisted the rehabilitation of degraded land and improved the establishment of secondary forest cover in protected areas.

The pattern of transition observed in the region suggested improved land-cover and therefore a gradual shift towards improved environmental quality. Extension work is needed to promote practices that preserve the natural forests, and restore the productive capacity of degraded agricultural and grazing lands. Practices such as agro-forestry or silvopasture are therefore encouraged. This approach calls for assisted intensification of agriculture so that food security is not compromised. Agricultural policies also need to be developed to mitigate pressure on forests and avoid future conversion of relatively fragile environments into cropland.

References

Adimassu Z., Gorfu B., Nigussie D., Mowo J., Hilemichael K., 2013. Farmers' preference for soil and water conservation practices in central highlands of Ethiopia. African Crop Science Journal, 21 (3): 781-790.

Adugna A., Abegaz A., 2016. Effects of land use changes on the dynamics of selected soil properties in North-eastern Wollega, Ethiopia. Soil, 2: 63-70.

Alexandratos N., 2005. Countries with rapid population growth and resource constraints: issues of food, agriculture, and development. Population and Development Review, 31 (2): 237-258.

Amanuel A., Mulugeta L., 2014. Detecting and quantifying land use/land cover dynamics in Nadda Asendabo Watershed, South Western Ethiopia. International Journal of Environmental Sciences, 3 (1): 45-50.

Angonese J. G., Grau H. R., 2014. Assessment of swaps and persistence in land cover changes in a subtropical Periurban Region, NW Argentina. Landscape and Urban Planning, 127: 83-93.

Awdenegest M., Holden N. M., 2009. Land cover change and gully development between 1965 and 2000 in Umbulo catchment, Ethiopia. Mountain Research and Development, 29: 265-276

Bahir A. L., Ahmed M. A., Antille D. L., 2015. Land suitability evaluation to optimize land management of small-scale farms in the Gerado Catchment, North-Eastern Ethiopia. Tropical Agriculture, 92 (1): 49-68.

Barbier E. B., Burgess C. J., Grainger A., 2010. The Forest transition: towards a more comprehensive theoretical framework. Land Use Policy, 27: 98-107.

Belay K. T., Van Rompaey A., Poesen J., Van Bruyssel S., Deckers J., Amare K., 2015. Spatial analysis of land cover changes in Eastern Tigray (Ethiopia) from 1965 to 2007: are there signs of a forest transition? Land Degradation and Development, 26: 680-689.

Bewket W., 2007. Soil and water conservation intervention with conventional technologies in north-western highlands of Ethiopia: acceptance and adoption by farmers. Land Use Policy, 24: 404-416.

Bewket W., Teferi E., 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land Degradation and Development, 20: 609-622.

Braimoh A. K., 2006. Random and systematic land-cover transitions in northern Ghana. Agriculture, Ecosystem and Environment, 113: 254-263.

Brink A. B., Eva H. D., 2009. Monitoring 25 years of land cover change dynamics in Africa: A sample based remote sensing approach. Applied Geography, 29: 501-512.

Carmona A., Nahuelhual L., 2012. Combining land transitions and trajectories in assessing forest cover change. Applied Geography, 32: 904-915.

Congalton R. G., Green K., 1999. Assessing the accuracy of remotely sensed data: principles and practices. CRC Press, New York.

Demeke N., 2013. Land use/land cover change and resource mapping of Borodo watershed and its surroundings, Oromia Regional Sate, Ethiopia. Ethiopian Journal of Natural Resources 13 (1 and 2): 21-42.

Food Agriculture Organization (FAO), 2015. Global forest resources assessment. How are the world's forests changing? Rome, Italy, FAO.

Izquierdo A., Grau R., 2009. Agriculture adjustment, land-use transition and protected areas in Northwestern Argentina. Journal of Environmental Management, 90: 858-865.

Kassa, H., Bekele M., Campbell B., 2011. Reading the landscape past: Explaining the lack of on-farm tree planting in Ethiopia. Environment and History, 17 (3): 461-479.

Lambin E. F., Geist H. J., Lepers L., 2003. Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environmental Resources, 28: 205-241.

Messay M. T., 2011. Land-use/land-cover dynamics in Nonno district, Central Ethiopia. Journal of Sustainable Development in Africa, 13 (1): 123-141.

Mohammed H., 2013. Impact of land use/land cover dynamics on the dried lake Alemaya watershed, Ethiopia. Ethiopian Journal of Natural Resources, 13 (1-2): 1-20.

Ndah T. H., Schuler J., Uthes S., Zander P., Triomphe B., Mkomwa S., *et al.*, 2015. Adoption potential for conservation agriculture in Africa: A newly developed assessment approach (QATOCA) applied in Kenya and Tanzania. Land Degradation and Development, 26: 133-141.

Nyssen J., Frankl A., Zenebe A., Deckers J., Poesen J., 2015. Land management in the northern Ethiopian highlands: local and global perspectives, past, present and future. Land Degradation and Development, 26 (7): 759-764.

Ouedraogo I., Barron J., Tumbo S. D., Kahimba F. C., 2015. Land-cover transition in northern Tanzania. Land Degradation and Development, 27 (3): 682-692.

Ouedraogo I., Runge J., Eisenberg J., Barron J., Sawadogo-Kaboré S., 2014. The Re-greening of the Sahel: natural cyclicity or human-induced change? Land, 3: 1075-1090.

Ouedraogo I., Tigabu M., Savadogo P., Compaore H., Oden P. C., Ouadba J. M., 2010. Land cover change and its relation with population dynamics in Burkina Faso, West Africa. Land Degradation and Development, 21 (5):453-462.

Pontius R. G., Shusas E., Mceachern M., 2004. Detecting important categorical land changes while accounting for persistence. Agriculture, Ecosystems and Environment, 101: 251-268.

Pretty J., Toulmin C., Williams S., 2011. Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability, 9: 5-24.

Schneider L. C., Geoghegan J., 2006. Land abandonment in an agricultural frontier after a plant invasion: the case of bracken fern in southern Yucatán, Mexico. Agricultural and Resource Economics Review, 35 (1): 167-177.

Singh Y. P., Nayak A. K., Sharma K. D., Singh G., Mishra K. V., Singh D., 2015. Evaluation of *Jatropha curcas* genotypes for rehabilitation of degraded sodic lands. Land Degradation and Development, 26: 510-520.

Siren A. H., 2007. Population growth and land use intensification in a subsistence-based indigenous community. Journal of Human Ecology, 35: 669-680.

Smith A. M. S., Drake N. A., Wooster M. J., Hudak A. T., Holden Z. A., Gibbons C. J., 2007. Production of Landsat ETM+ reference imagery of burned areas within Southern African savannahs: comparison of methods and application to MODIS. International Journal of Remote Sensing, 28 (12): 2753-2775.

Teshome A., De Graaff J., Ritsema C., Kassie M., 2014. Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the north western Ethiopian highlands. Land Degradation and Development, 27 (4): 884-898.

Urgesa A. A., Abegaz A., Bahir A. L., Antille D. L., 2016. Population growth and other factors affecting land-use and land cover changes in north-eastern Wollega, Ethiopia. Tropical Agriculture, 93 (4): 298-311.

Wood E. C., Tappan G. G., Hadj A., 2004. Understanding the drivers of agricultural land use change in south-central Senegal. Journal of Arid Environments, 59: 565-582.

Yodit A., Fekadu B., 2014. Examining drivers of land use change among pastoralists in Eastern Ethiopia. Journal of Land Use Science, 9 (4): 402-413.

Zucca C., Wu W., Dessena L., Mulas M., 2015. Assessing the effectiveness of land restoration interventions in dry lands by multi-temporal remote sensing-a case study in Ouled Dlim (Marrakech, Morocco). Land Degradation and Development, 26: 80-91.