

Agricultural landscape change impact on the quality of land: An African continent-wide assessment in gained and displaced agricultural lands

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ABSTRACT

Agricultural land area is increasing globally despite the loss of productive agricultural lands in some world regions. We examine the case of Africa where the knowledge about major agricultural land transitions and the impacts on the quality of land is still very limited. A comprehensive assessment of change in agricultural landscapes was conducted at the African continental scale. We identify influencing factors and model the quality of land associated with agricultural land gains and losses between 2000 and 2018. Land quality was established based on spatially-explicit analysis of varying Net Primary Productivity, soil organic carbon content, crop suitability and percent yield change for major crops of global importance grown across Africa such as maize, rice, soybean, wheat, and alfalfa. Distance to settlements was important in explaining agricultural land dynamics. Most land areas that transitioned to cropland in Africa were associated with large distances away from major roads. Poor access to major roads suggests the remoteness of gained croplands. Land quality was better in gained croplands than in those lost, whereas gained grasslands were of lesser quality compared to areas of grassland loss. Five typologies of African countries were developed based on net yield and amount of land cultivated per crop in cropland change areas. Type 1 typifies net yield increase and cultivated land decrease, while type 2 is characterized by yield increase consequent upon cropland expansion. Net yield and land remain unchanged in type 3, while in type 4 cultivated land increased but yield decreased as in 40% of African countries for maize, and in type 5, both yield and land area decreased. This study thus provides evidence about the quality of land in gained and lost agricultural areas and generalizable insights on their dynamics across Africa.

1. Introduction

Grasslands comprising pastures and rangelands, rainfed and irrigated croplands, and permanent croplands are expanding globally (Eigenbrod, 2020; Molotoks et al., 2018; United Nations 2021, 2021). This increasing trend stems mainly from increased demand for agricultural products and changing dietary preferences (Vos et al., 2019; Marques et al., 2019). Agriculture is a major factor driving global environmental degradation (Conijn et al., 2018; Scholes et al., 2018; Marques et al., 2019). In many world regions, agricultural lands are also being lost, particularly those near human settlements (Akinyemi, 2013; Marconcini et al., 2020). Increasing global population, urbanization, and non-food agricultural production amongst other human activities are driving the loss of productive agricultural lands (Creutzig et al., 2019) of varying magnitudes in China (Li et al., 2018), Europe (Tóth, 2012), and Africa (Jayne et al., 2014). Moreover, areas of projected urban expansion intersect some of the world's most productive croplands, particularly in Asia and Africa (D'Amour et al., 2017). Agricultural land-use and change are therefore major considerations for sustainability transitions (Heck et al., 2018; Meyfroidt et al., 2018; Smith et al., 2019). Practicing agriculture sustainably with minimal negative environmental impacts is a challenge faced in the twenty-first century, especially in biodiverse, tropical regions.

The case of continental Africa is examined considering its cropland expansion frontiers of global note (Creutzig, 2019; Eigenbrod, 2020; Winkler et al., 2021). Creutzig et al. (2019) noted that 39% of global cropland expansion areas, between 2000 and 2010 (representing 29% of cropland change hotspots globally), are in the Guinean Savannah of West Africa. Agricultural land expansion in Africa is occurring in the context of heightened population pressure, foreign and domestic land

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acquisitions (Keulertz and Woertz, 2015), and increasing distal demands for land-based products (Dou et al. 2020; Brobbey et al., 2020). Africa plays a prominent role globally in large-scale agricultural land acquisition and smallholder agriculture, some under frontier conditions (Dou et al., 2020; Eigenbrod, 2020).

Africa has fewer land-use studies compared to other world regions (Verburg et al., 2015). There is a dearth of knowledge on the dynamics (i.e., gains, losses, and net change) of agricultural land change (ALC) and the quality of gained and lost agricultural lands. We argue that with pressure mounting to halt biodiversity loss and stem land degradation in agricultural areas, promoting sustainable agriculture requires not only an understanding of agricultural land-use change but also the impacts on land quality. Global and regional studies (e.g., Alcamo et al., 2011; Xiong et al., 2017; Creutzig et al., 2019) provide limited insights about agricultural land-use change in Africa (Midekisa et al., 2017). The inference is often made to agriculture as one of many land categories and assessment of cropland and/or grassland extents are often for a single time. The latter is a major drawback for monitoring ALC in Africa (e.g., Pérez-Hoyos et al., 2020). Monitoring requires land-use time-series, systematically produced datasets using similar methodologies and classification schemes. Hence, knowledge about ALC as well as the quality of lands converted for agricultural purposes and of lands from which agriculture is displaced in Africa is limited.

To address these gaps, we analyze ALC and the associated land quality between 2000 and 2018. Land quality was analyzed based on the change in Net Primary Productivity (NPP), Soil Organic Carbon content (SOC), percent change in crop yield and Crop Suitability Index (CSI) for five crops, assuming low-input, rainfed conditions (maize - *Zea mays*, rice - *Oryza sativa*, soybean - *Glycine max*, wheat - *Triticum* spp. and alfalfa - *Medicago sativa*). These crops of global importance were chosen because they are produced and consumed across Africa. NPP connotes the land's biological productive capacity (e.g., for providing food, fiber) (Clark et al., 2001); SOC is a proxy for soil health and fertility with implications for agriculture; crop yield and land suitability for cultivation are productivity metrics (Hermans-Neumann et al., 2017; Scholes et al., 2018). In the following sub-sections, we describe land-uses to which agricultural lands (i.e., cropland and grassland) are transitioning, the social-ecological factors explaining ALC as well as the land quality in areas of agricultural gain and loss in Africa.

2. Materials and methods

Using indicators derived from multiple datasets, we assess transitions between land uses with a particular focus on agricultural land change and land quality in change areas.

2.1. Indicators

Indicators for this study utilized the highest quality data available (Table 1). The study period of 2000 to 2018 was not maintained for all analyses due to data availability (periods used for each indicator are specified in Table 1). The extent and change in agricultural lands between year 2000 and 2018 were computed from the European Space Agency Climate Change Initiative land cover (CCI-LC) (Santoro et al., 2017). CCI-LC is a consistent time-series of multi-sensor annual maps available from 1992 to 2019. Unlike single-year and single-sensor derived datasets, these time-series were developed with comparable methods and are sufficiently long to capture ALC. Studies have used the CCI-LC for landscape change and degradation (e.g., Jiang and Yu, 2019; Nowosad et al., 2019; Akinyemi et al., 2020).

Factors potentially driving ALC were selected based on their relationships to agriculture. The loss of prime agricultural lands and natural covers has been linked to proximity to settlements, connoting market access and major roads (D'Amour et al., 2017). With the lowest density of paved roads in Africa, in comparison with other regions of the world (FAO, 2002), we included a broad range of road types in the

analysis of proximity to major roads. For better coverage, classes subsumed under major roads included highways, primary, secondary, tertiary and local/urban roads as contained in CIESIN's gROADSv1 data. Proximity to perennial rivers/waterbodies typifies the potential for irrigation and water transport of farm input and produce. Projected population density data of 2020 was used to capture human pressure on agricultural lands. We consider the influence of rainfall variability on rainfed agriculture using the monthly CRU precipitation data (2000–2018) (Harris et al. 2020). Physiographic influence on agriculture was captured using elevation. High altitudes are less preferred for agriculture due to constraints from steepness and frost.

For the quality of displaced and gained agricultural lands, we use NPP, SOC, CSI, and crop yield (Table 1). Annual MODIS NPP image datasets of the year 2000 till 2018 were used. MODIS NPP is a composite image of the 8-day Net Photosynthesis, and gap-filled data with each pixel having undergone quality control (Running & Zhao, 2019). For soil quality, variation in SOC was used as higher values of SOC connote better soil health (Hengl et al., 2017). The GAEZ CSI data was used to assess land suitability for crops. Four food crops (i.e., maize, rice, soybean, and wheat), and alfalfa, a fodder crop, were selected as these are widely produced and consumed across Africa. These crops are equally important as commodity crops for international trade (Lizumi et al., 2014). The CSI considered climate constraints, crop calendar, agro-climatic yields, and agro-ecological suitability and productivity for cultivated land areas. Percent yield change was used to gauge crop productivity (Ray et al. 2013). All datasets were resampled to 5 arc minutes ($\sim 10 \text{ km}^2$) for compatibility with the GAEZ.

2.2. Methods

Land cover change, the driving factors, and characterized land quality in ALC areas at the African continental scale were examined between 2000 and 2018.

2.2.1. Land cover transitions

Thirty-six land categories present over Africa in the CCI-LC data were aggregated into seven categories. These are tree-covered area, grassland, cropland, wetland, artificial surface, otherland, and waterbody (Table S1). This classification scheme is based on the correspondence of the CCI-LC land categories with those of the United Nations Convention to Combat Desertification (Santoro et al., 2017). Using these land categories makes results comparable to similar studies in other world regions and relevant for use in different domains requiring land cover change data over Africa. Interpreting land transitions with results from local sites across Africa provided insights into the dynamics in gained and displaced agricultural lands.

Land cover transitions to and from agriculture and between cropland and grassland were identified and quantified during the time interval between the initial (2000) and final time points (2018). The transition matrix depicts both land categories that transitioned from a certain category i to category j and categories that remain unchanged (i.e., persisted) over the 19-year study period. Land transitions and persistence between these initial and final time points were computed as in Eqs. (1) – (3) with the mathematical notations explained in Table 2.

$$C_t = \sum_{j=1}^N \left[\left(\sum_{i=1}^N C_{ij} \right) - C_{jj} \right] \quad (1)$$

$$L_{ti} = \left[\left(\sum_{j=1}^N C_{ij} \right) - C_{ii} \right] \quad (2)$$

$$G_{ij} = \sum_{j=1}^N \left[\left(\sum_{i=1}^N C_{ij} \right) - C_{jj} \right] \quad (3)$$

Table 1

Datasets used in this study.

Dimension	Indicator	Relationship to ALC	Unit/year	Data	URL
Agricultural land change	Cropland and grassland extent and dynamics	Displaced and gained agricultural lands	300 m, 2000–2018	European Space Agency Climate Change Initiative land cover (CCI-LC) v2.0.7	https://www.esa-landcover-cci.org/
Quality of agricultural land change (ALC) areas	Net Primary Productivity (NPP) mean and trends	NPP captures the land's biological productive capacity (Clark et al., 2001)	kgC m ² yr ⁻¹ , 500 m (2000–2018)	Annual MODIS NPP (Gap-filled) MOD17A3HGF.006	https://doi.org/10.5067/MODIS/MOD17A3HGF.006
	Net percent yield change	Rice, maize, soybean, wheat – crops grown across Africa	Rate of yield change (% yr ⁻¹) 5' x 5' (~10 km ²), 1989–2008	EarthStat	http://www.earthstat.org/yield-trends-changes-maize-soybean-rice-wheat/
	Crop suitability index (CSI)	Land suitability for maize, rice, soybean, wheat, alfalfa	5' x 5' (~10 km ²), 2000, rainfed (1960–1990 baseline)	Global Agro-ecological Zones (GAEZ) v.3	http://www.gaez.iiasa.ac.at/
	Soil organic carbon content (SOCc)	Soil fertility and health	(%: g/kg), 250 m (~2000), 0–30 cm depth	International Soil Reference and Information Center (SoilGrids)	https://www.isric.org/explore/soilgrids/faq-soilgrids-2017
Biophysical	Rainfall variability	High rainfall variability poses risk to rainfed agriculture (Hermans-Neumann, et al. 2017)	2000–2018 (monthly precipitation data)	Climatic Research Unit (CRU-TS) precipitation data (v4.03)	https://catalogue.ceda.ac.uk/uid/89e1e34ec3554dc98594a5732622bce9
	Elevation	Higher elevations and steeper slopes are less preferred for agriculture	30 arc-second (~1 km at the equator) Digital Elevation Model of Africa	USGS Center for Earth Resources Observation and Science (EROS) (GTOPO30)	http://databasin.org/datasets/2965da954b114ff3b47621e99e3b29ba
Economic effects due to proximity	Distance to major road	Proximity to major roads enhances access such as to market. Accessible agricultural lands are easier to reach, hence prone to conversion (Laurance and Arrea, 2017; Riggio et al., 2020)	Major roads comprise functional classes 1 to 5 (5 km Euclidean distance), 2013	CODATA Global Roads Data Development Task Group Global Roads Inventory Dataset (gROADSv1)	http://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1
	Distance to settlement	Agricultural lands near settlements are prone to conversion due to urban expansion. Associated land transitions to agriculture in settlement vicinities link population growth in settlements to increased demand for agricultural produce (Herrmann et al., 2020)	Settlement extent (5 km Euclidean distance), 2017	Global Rural-Urban Mapping Project Urban Extent Polygons (GRUMPv1.1)	https://doi.org/10.7927/H4Z31WKF
	Distance to perennial river/waterbody	Nearness to rivers (particularly perennial) enhances agricultural land's access and irrigation potential (You et al., 2011)	Perennial river and waterbody (5 km Euclidean distance), 2014, 2015	FAO rivers in Africa, RCMRD water bodies in Africa	FAO rivers in Africa, http://geoportal.rcmrd.org/layers/servir%3Aafrica_water_bodies
Social	Human population density	Population density pressure on land can decelerate/accelerate land conversion (Eigenbrod, 2020; Riggio et al., 2020)	30 arc-second (~1 km at the equator), projected population density (2020), %	Gridded Population of the World density (GPWv4.11)	https://doi.org/10.7927/H49C6VHW

Table 2

Mathematical notation used for land transition and persistence following [Akinyemi et al. \(2017\)](#).

Symbol	Description
T	number of time points used in this study, two time points (2000 and 2018)
t and $t + 1$	indexes for the initial and final time points
Y_t and Y_{t+1}	year at the initial time point t (in this case the year 2000) and year at the final time point $t + 1$ (in this case the year 2018) of the interval $[Y_b, Y_{t+1}]$
N	number of land categories
i	index for a land category at an interval's initial time point
j	index for a land category at an interval's final time point
C_t	land-use change during the interval $[Y_b, Y_{t+1}]$
C_{tij}	proportion of the landscape that transitioned from category i to category j during interval $[Y_b, Y_{t+1}]$
C_{iti}	proportion of the landscape that persisted as category i during interval $[Y_b, Y_{t+1}]$
L_{ti}	loss of i during interval $[Y_b, Y_{t+1}]$
G_{tj}	gain of j during interval $[Y_b, Y_{t+1}]$

2.2.2. Drivers of agricultural land change

Principal Component Analysis (PCA) was computed to examine the influence of factors relating to underlying agricultural land-use change patterns. PCs were interpreted as defining certain dimensions that are important in explaining variability in the four ALC areas ([Jolliffe, 2002](#)). The coefficient of rainfall variability (CV) was computed to capture rainfed agriculture's risk to climate since high CV indicates regions under environmental pressure ([Hermans-Neumann et al., 2017](#)). Differentiation into growing seasons was not made as the growing season differs across Africa. Instead, the mean annual rainfall was computed from the monthly data to analyze CV from 2000 to 2018. For proximity indicators such as distance to major roads, and perennial rivers/water bodies, a 5 km buffer was used. All datasets were standardized before PCA to make them comparable. We kept PCs with more explanatory power (cumulatively 90% or more of the variance in the data). A distance range for agricultural lands within and beyond 100 km to a major road was also applied to land areas gained and lost by croplands and grasslands. Our selection of this distance range (i.e., 100 km) was based on the use in examining the impacts of roads on farm size and/or farmer's market participation in Africa ([Acheampong, 2016](#); [Nagler and](#)

[Naude., 2014](#)). Examples from Ghana revealed that distances over which food crops were transported from farms to major cities such as Accra, ranged from 120 km to 200 km for yam and plantain, 360 km for tomato and 420 km for maize ([Hine et al., 1983](#); [Hine and Ellis, 2001](#)).

2.2.3. Quality of agricultural land change areas

Gridded NPP, SOCC, percent change in crop yield and crop suitability were intersected with the boundaries of the four areas of ALC to analyze the quality of land in agricultural change areas. NPP mean, computed as the average NPP, and trends were analyzed from the annual time series between 2000 and 2018. The significance was tested at the 95% confidence level using the Mann-Kendall non-parametric test. Ranging from -1 to $+1$, tau (τ) values greater than 0 indicate a continually increasing trend, whereas values less than 0 indicate a continually decreasing trend ([de Jong et al., 2011](#)). Classifying the NPP mean and trend by quartiles, pixels in any ALC area, within the lowest two quartiles for each indicator, were identified as vulnerable. It is assumed that indicators in the lowest quartiles imply the vulnerability of social-ecological systems in such regions to degradation and impacts from climate variability and change ([Hermans-Neumann et al. 2017](#)).

Changes to agricultural land-use were related to changing NPP conditions to illustrate how land quality can be impacted in areas of ALC ([Fig. 1](#), I-III).

Based on Eqs. (1)–(3), we illustrate land-use change with increasing NPP (case I), differing impacts of change in agricultural lands on NPP (case II), and NPP in areas of land-use persistence (case III). Case I illustrates an increase in NPP in cropland loss areas as pixel i , which was cropland in the initial time point ($Y_t = Y_{2000}$), was converted to tree-covered area j as of the final time point ($Y_{t+1} = Y_{2018}$). Based on the literature (e.g., [Devaraju et al., 2015](#)), an increase in NPP during the time interval $[Y_b, Y_{t+1}]$ is most likely when croplands get converted to tree-covered areas in the tropics. Case II portrays the possibility of differing NPP levels over time, (e.g., $Y_{2000}, Y_{2001}, \dots Y_{2018}$) for a cropland pixel i at various degraded states before eventual conversion to grassland j . NPP trends depend on various factors (e.g., NPP level during the cropland's relatively non-degraded state, how much degraded the cropland was before conversion to grassland, when the conversion took place and the replacement cover, amongst other factors). For example, NPP levels can decline from being relatively steady as the cropland

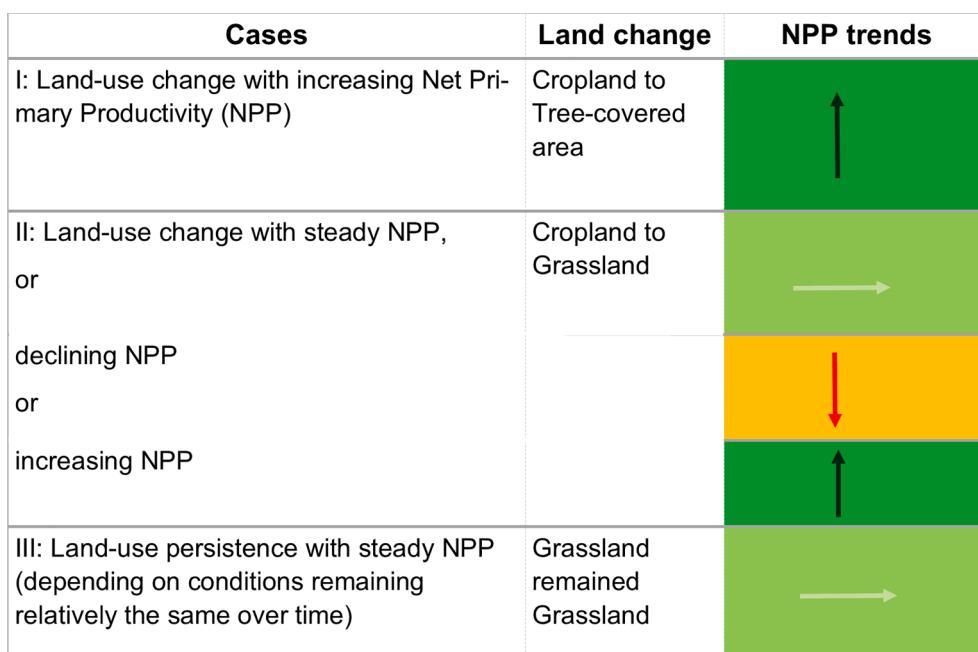


Fig. 1. Differing NPP levels, as a proxy for land quality, in areas of agricultural land change and persistence.

becomes less productive due to degradation, leading to abandonment. As grassland succession occurs on abandoned cropland, NPP in the transitioned grassland may likely decline initially if lower than that of the replaced crops but increase over time in the established grassland. Case III is an example of a persisting grassland with steady NPP values on the assumption that conditions remain relatively the same during the time interval $[Y_b, Y_{t+1}]$.

Computing NPP mean over these cases may mask variations in NPP due to outlier effects on the mean but NPP trends may better capture the variations in NPP as an increase, steady or decline in areas of persisting and changing agricultural lands over time.

Land quality in displaced and gained croplands and grasslands was evaluated per African country. Net percent change in yield was computed for each crop in areas of cropland loss and gain. We clustered African countries by crop yield and the amount of cultivated land under low input, rainfed cropping, which characterizes smallholder agriculture in Africa (Eigenbrod, 2020; Lowder et al., 2016). For cropland change areas, CSI was composited across croplands suitable for maize, rice, soybean and wheat using cross-tabulation, whereas for grassland only the CSI for alfalfa was used. The nine crop suitability categories of the GAEZ were reclassified as follows: 1 = Very high, 2 = High, 3 = Moderate, 4 = Marginal, 5 = Unsuitable (see Table S2 for details of the reclassification).

3. Results

Areas of ALC, where land-uses were converted to and from agriculture (i.e., croplands and grasslands), and areas of persistence, where the land-use remained unchanged, were quantified between 2000 and 2018. These formed the basis for identifying major transitions involving agriculture, the driving factors of observed changes and the modelling of

changing land quality in ALC areas across the continent.

3.1. Land cover change

Areas of persistence, where no transitions occurred, in croplands and grasslands amounted to 15% and 7% in Africa respectively. Extent of agricultural lands are depicted in Fig. 2a, areas of category loss and gain were also presented (Fig. 2b, c). Lost agricultural lands amounted to 329,492 km² (cropland = 176,017 km², grassland = 153,475 km²), whereas gained agricultural lands amounted to 570,246 km² (cropland = 411,986 km², grassland = 158,260 km²). Fig. 2d depicts the persistence, loss and gain per land category. Net losing land categories were grassland, otherland, and wetland (see Table S3 for the transition matrix).

3.2. Major agricultural land transitions (2000–2018)

Seven major transitions, involving cropland and grassland, were identified (Cases A – E in Fig. 3, see Table S4 for the data).

Case A. Transition of croplands to artificial surfaces (Fig. 3A). In the period 2000–2018, artificial surface, represented by human settlement and infrastructure, derived 28% (14,471 km²) of its size from cropland and 8% (4,251 km²) from grassland. The Monrovia (Liberia), Abidjan (Côte d'Ivoire), Accra (Ghana), Lagos (Nigeria), Ibadan (Nigeria), Benin-City (Nigeria), and Douala (Cameroon) axis, which is an African hotspot of agricultural land loss, illustrates Case A. **Case B:** Transition of otherland (i.e., bare areas, sparse vegetation and shrubland) to cropland (Fig. 3B). Instances of the conversion of otherland into cropland (109,259 km² – 2%) were mostly in Egypt, Tunisia, Algeria, and Morocco. **Cases C and G:** Transition of grassland to otherland (Fig. 3C) and the transition of otherland to grassland (Fig. 3G). Land lost by

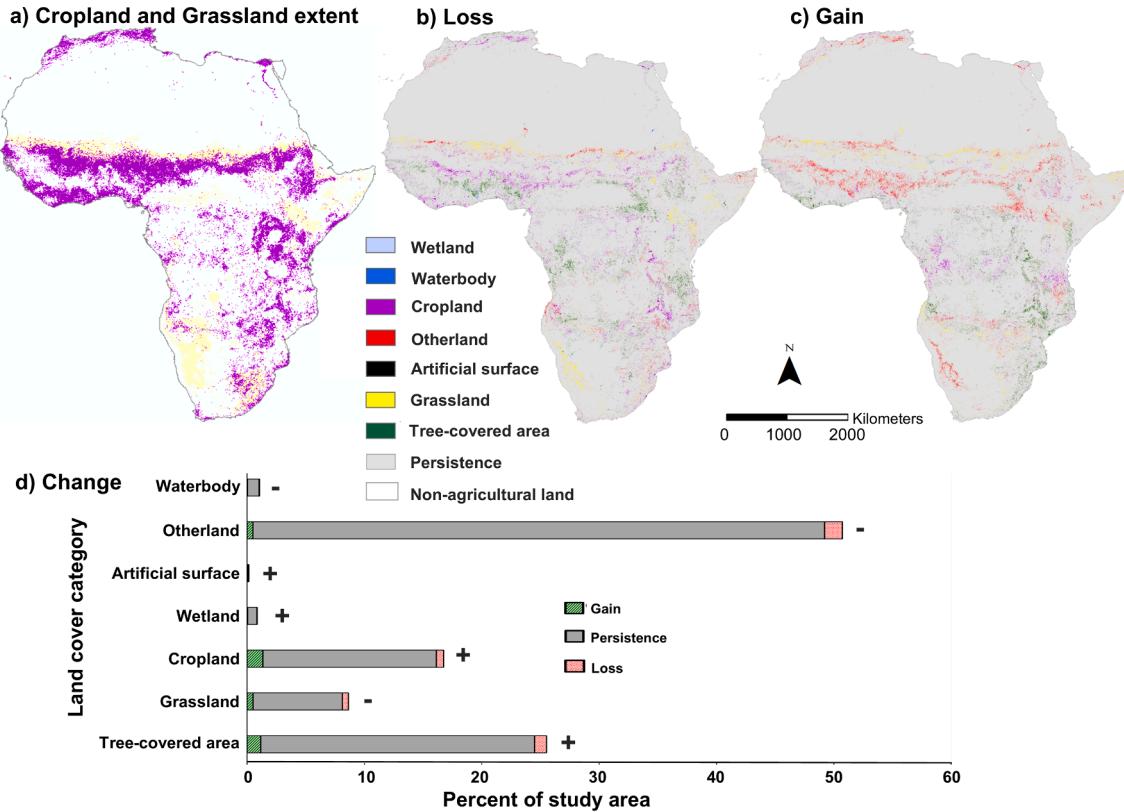


Fig. 2. Land cover change map between 2000 and 2018, a) Agricultural lands comprising cropland and grassland as of 2018 (areas in white are non-agricultural areas), b) Loss areas represent locations where the land categories shown in the legend were converted to other uses, c) Gain represents the land use to which the lands in panel b were converted. Areas of persistence are locations where the land-use remained unchanged (2000 – 2018), and d) Change budget showing each category's gain, persistence and loss (+ means net gain, – means net loss over the study period).

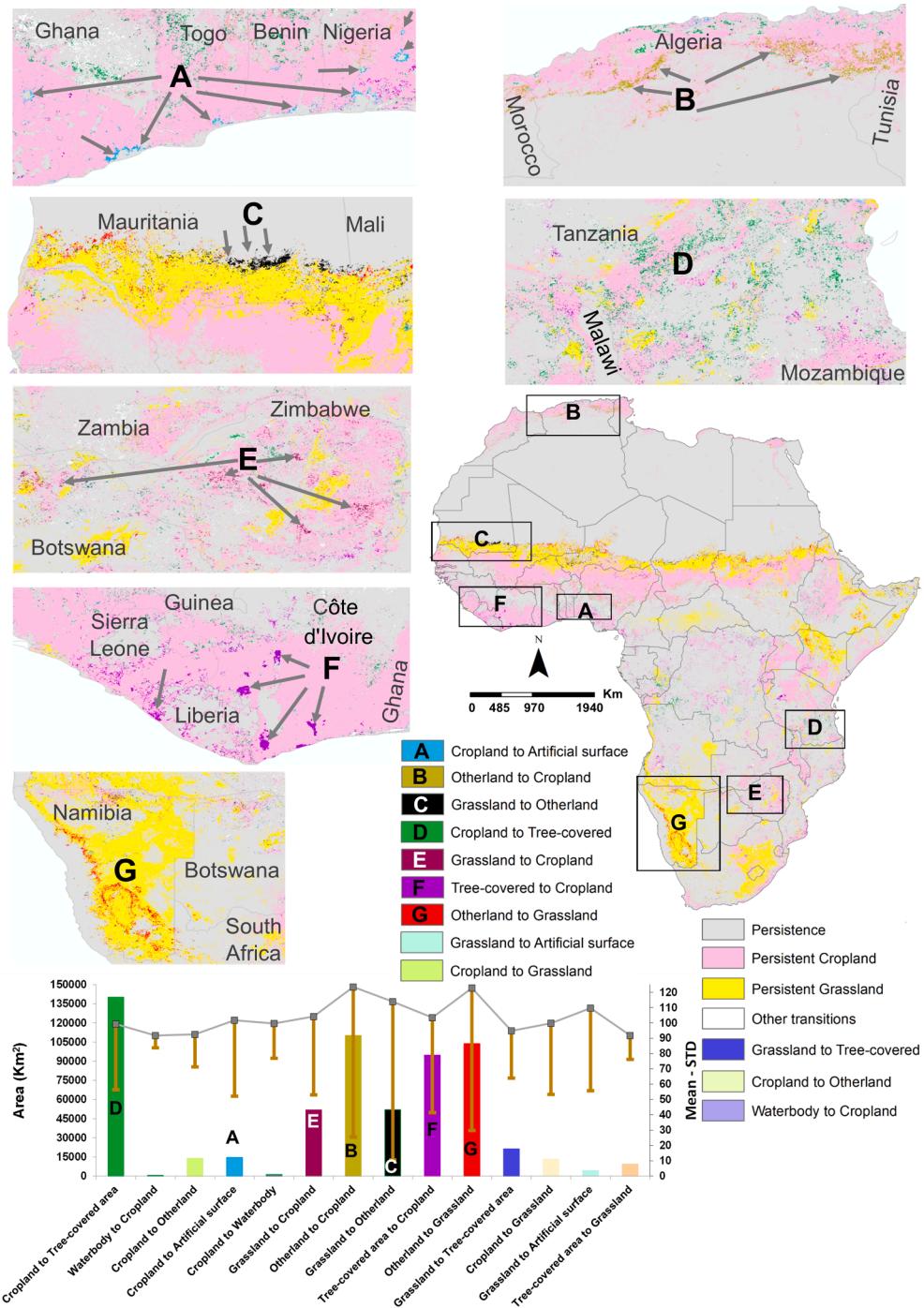


Fig. 3. Major agricultural land transitions (A to G). For example, arrows in box letter A point to areas of settlement expansion at the expense of cropland. The bars show each transition's size (graph's left y-axis) alongside the mean (line, graph's right y-axis) and standard deviation (STD) as error bar.

otherland to grassland amounted to 104,104 km² (4% of Otherland's size in 2000), whereas grasslands in 2000 that were converted to otherland in 2018 amounted to 52,911 km² (0.1%). Instances of grassland-otherland exchanges were found in the Sahelian northern fringes, Kenya, eastern Ethiopia, Mali, Mauritania, and Namibia. **Cases D and F:** Transition of cropland to tree-covered area (Fig. 3D) and transition of tree-covered area to cropland (Fig. 3F). The amount of cropland in 2000 converted to tree-covered areas in 2018 was 144,804 km² (2%) such as in Tanzania, Uganda, and Rwanda. Cropland's gain from tree-covered area (98,044 km², 2%) occurred mostly in the Guineo-Congolian (Sierra Leone, Liberia, Nigeria, Cameroon) and the Congo Basin rainforest (Democratic Republic of Congo – COD, Turubanova et al., 2018). **Case**

E: Transition of grassland to cropland (Fig. 3E). Croplands gained from grassland amounted to 52,278 km² (1%) and this transition mostly occurred in eastern Botswana, western Zimbabwe and South Africa.

3.3. Drivers of agricultural land change

Regarding drivers of ALC in Africa, three dimensions were identified as important from the PCA eigenvectors explaining the largest share of variation in the data (Table 3). These are accessibility exemplified by access to major roads having the highest loading on the first component (PC1), distance to settlements (PC2) and PC3 with the highest positive loading from elevation. PC3 reflects the role of elevation on ALC. All

Table 3
Results from PCA.

Variables	Components														
	Entire study area			Cropland gain			Cropland loss			Grassland gain			Grassland loss		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
	A	S	E	S	A	W	S	A	W	A	S	W	E	A	W
Elevation	-0.06	0.10	0.87	-0.03	-0.02	0.07	0.01	-0.21	0.24	-0.08	-0.03	0.93	-0.08	-0.02	0.34
Distance to settlement	0.04	0.97	-0.16	0.96	0.29	-0.02	0.98	0.02	-0.19	0.15	0.98	-0.04	0.03	0.60	0.79
Distance to perennial river	-0.08	0.17	0.25	0.03	-0.03	0.96	0.03	-0.06	-0.01	-0.01	0.15	0.08	0.19	0.06	0.03
Distance to major road	0.99	-0.01	0.12	0.30	-0.96	-0.04	0.19	-0.32	0.88	0.99	-0.15	0.03	0.07	0.79	-0.61
Distance to perennial waterbody	-0.12	0.12	0.27	0.01	0.02	0.27	0.05	0.92	0.36	0.04	0.95	-0.30	-0.01	0.02	0.94
Human population density	-0.00	-0.00	0	-0.00	-0.00	-0.00	-0.01	0.01	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00
Rainfall variability	0.02	-0.00	-0.25	-0.01	-0.00	0.004	-0.02	0.03	-0.01	0.00	0.01	0.03	-0.01	-0.00	0.01
Total variance	40.4	33.3	8.6	43.6	26.5	11.5	53.5	13.5	45.2	24.4	11.9	9.5	44.2	30.2	9.6
															8.9
															92.9 %

Note: A – Accessibility, E – Elevation, S – Settlement, W – Waterbody.

three dimensions connote that agricultural lands that are proximal to settlements with good access to major roads and at optimal elevation are more likely to be converted to other uses. Influencing factors at the level of each ALC area (i.e., cropland and grassland gains and losses) were examined. In cropland loss and gain areas, settlement development, proximity to perennial rivers/water bodies, and access to a major road were the important dimensions, only major road access had a high but negative loading in cropland gain areas. Distance to a major road, waterbody, settlement development and elevation were important for explaining grassland dynamics.

The PC2's high negative loading of access to a major road in cropland gain areas hints that cropland gain areas have an element of remoteness from major roads. A closer examination of this relation (Fig. 4) exposes a double effect — although 36.3% of cropland gain areas were found within a 100 km range of major roads, a larger proportion (63.7%) of cropland gain areas were farther (>100 km) from major roads. The majority of areas lost by cropland (56.6%) were found within 100 km of major roads. These patterns in croplands contrast with those of grasslands with the minority of gained and lost grasslands found within ≤ 100 km of a major road.

3.4. Characterizing the quality of agricultural land change areas

Changes in the indicators of land quality in agricultural change areas were used to gauge the quality of land agriculture gained and lost in Africa during the study. We captured how biophysical conditions and crop productivity differed between ALC areas using NPP mean and trends, SOC_c, CSI (Fig. 5) and net percent change in yield.

3.4.1. Net primary productivity in areas of agricultural land change

Areas gained by cropland in 2018 had higher mean NPP than areas of loss (Fig. 5a). Most areas gained by cropland (65%) were within the two lowest quartiles of mean NPP compared to 85% of cropland loss areas. Examples of cropland gain areas were in the Sudan and Sahel savannahs in West Africa, and areas converted to cropland from otherland in North and Southern Africa. Grassland gain areas in the two lowest quartiles amounted to 85% compared to 62% in grassland loss areas. Considering that low NPP supply implies vulnerability to land degradation, we examined NPP trends in all ALCs (Fig. 5b). NPP trend in 66% of cropland gain areas decreased compared to 62% in displaced croplands. Much of the areas with decreasing NPP trends were gained croplands from the Guineo-Congolian (West Africa) and Congo basin rainforests, whereas some areas of cropland gain in the Sahel experienced increasing NPP trends. In areas of grassland gain, NPP trends decreased (81%), whereas NPP decreased in 59% of areas where grassland was displaced. Per ALC class, maximum NPP value ($\text{kgC m}^{-2} \text{ yr}^{-1}$) and maximum change, respectively, are as follows: cropland gain (2.32, 0.60), cropland loss (1.40, 0.57), grassland loss (1.6, 0.63), and grassland gain (1.71, 0.57).

3.4.2. Soil organic carbon content in areas of agricultural land change

SOC content (SOC_c, %: g/kg) is intrinsically connected to soil quality (Mattina et al., 2018). Fig. 5c shows that more areas in displaced croplands had SOC_c within the two lowest quartiles (97%) compared to 94% in gained croplands. In absolute terms, SOC_c in ALC areas was highest in gained croplands (254 g/kg) found in Gabon, southern Mozambique, along the West African coast and COD but lowest (137 g/kg) in displaced croplands found in Congo, COD, southern Tanzania. In grasslands, the highest maximum SOC_c (209 g/kg) was in a displaced grassland found eastern Angola compared to 174 g/kg in grassland gain areas such as in Burundi and Tanzania. High maximum SOC_c values are obscured as most areas across Africa had values within the lowest two quartiles.

3.4.3. Crop suitability in agricultural land change areas

The quality of land using the composite CSI (maize, rice, soybean, wheat) in croplands, and alfalfa in grasslands differed between ALC

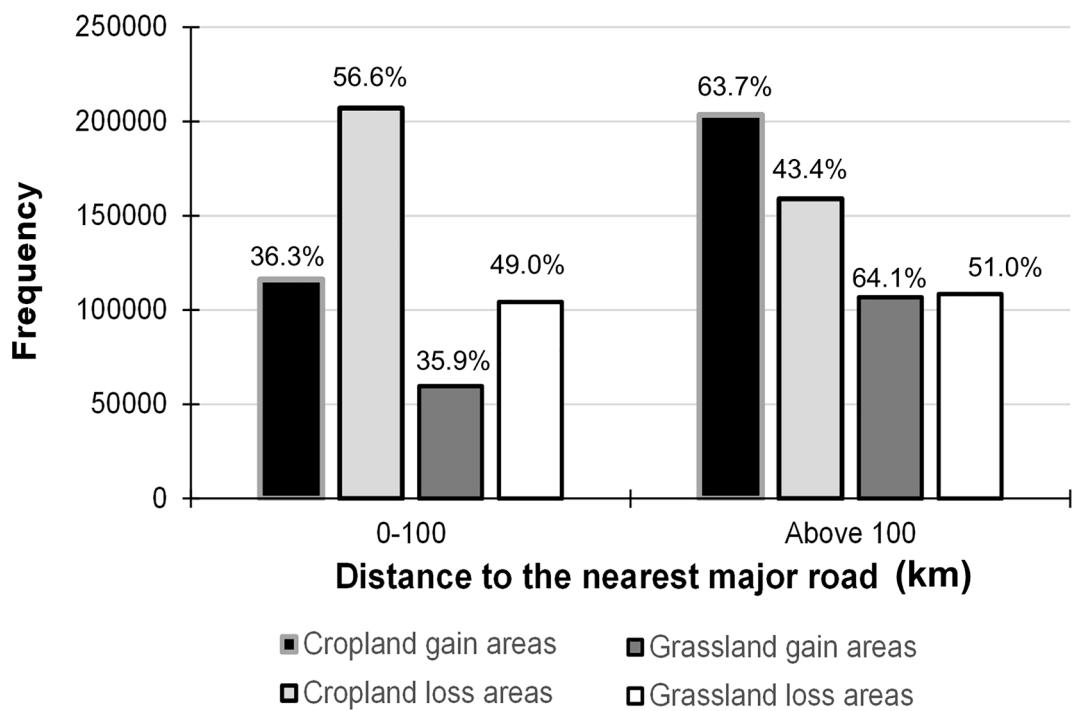


Fig. 4. Relating agricultural land change areas with proximity to major roads in Africa.

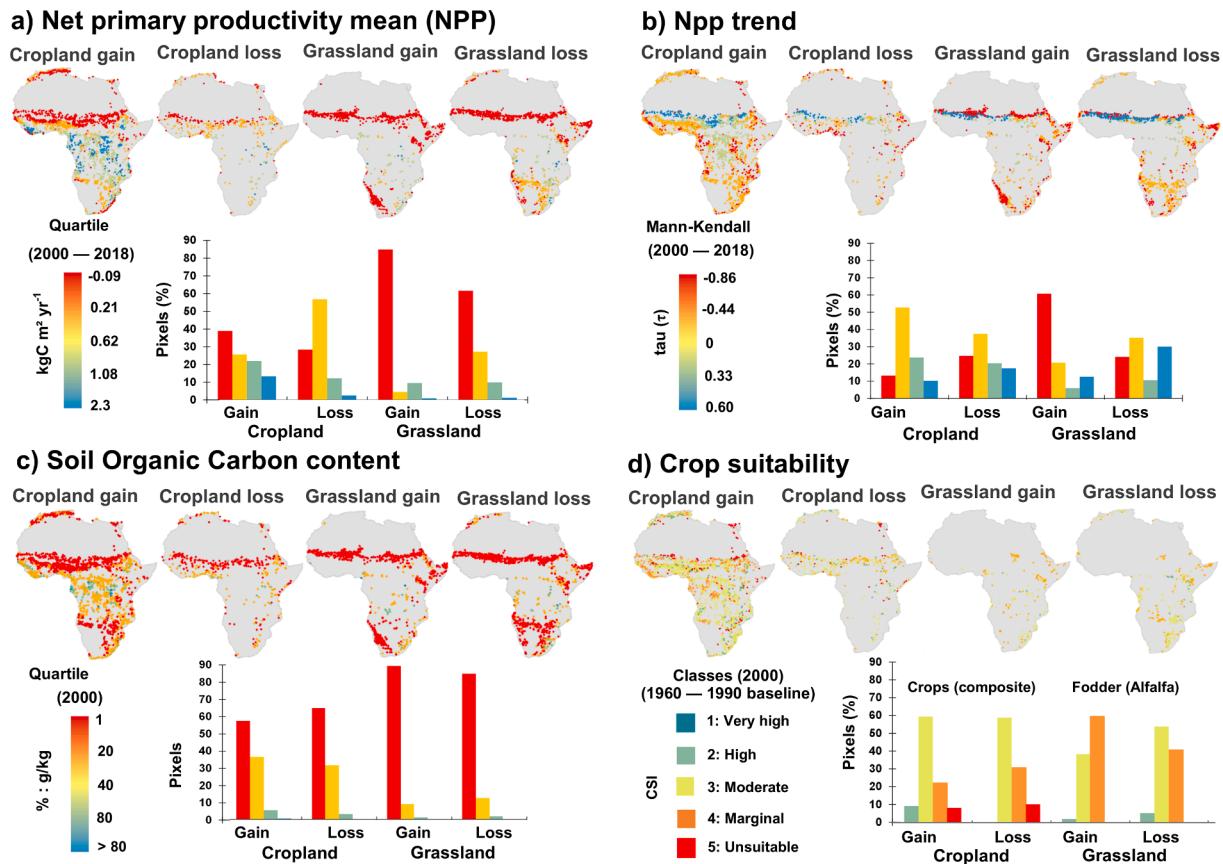


Fig. 5. Quality of land in areas of agricultural gains and losses a) Mean NPP, b) Trends in NPP, c) SOC content, d) Suitability for cultivating crops. Crop composite in croplands comprises maize, wheat, rice, and soybean.

areas (Fig. 5d). Sixty-nine percent (69%) of areas of cropland gain had high and moderate suitability such as in Nigeria, Cameroon, COD, western Angola, southwest Kenya, Morocco, and northern Algeria, compared to 59% in displaced croplands. More grassland areas with high and moderate suitability were lost (59%) than gained (41%) such as in Zimbabwe, South Africa, and Eswatini.

3.4.4. Net percent change in crop yield and cultivated land

The net percent change in yield (i.e., increases or decreases) was related to net cultivated land area for the four crops in cropland change areas (Fig. 6) (see data in Table S5 and Fig. S1-a-d for an example showing wheat cultivation per African country).

For each crop in areas of cropland gain and loss, we associated African countries with one of five clusters comprised of varying combinations of net yield and cultivated land area (Fig. 6). Cluster 1 has a net increase in yield and a decrease in cultivated land in areas of cropland gain and loss. For example, the net maize yield increased in Gambia, Somalia and Uganda while land under maize cultivation decreased despite higher yields, implying agricultural intensification. Cluster 2 is characterized by yield increase consequent upon cropland expansion. For maize, 18% of countries in Africa such as Zambia, Niger and Morocco, fit into this cluster of agricultural extensification. For rice, most central and east African countries fit in this cluster 2. Cluster 3 is defined by countries where net yield remained the same, whereas net cultivated land area remained unchanged or increased (e.g., Sierra Leone, Ghana, Tanzania, and COD). In cluster 4, cultivated land increased but yield decreased. Most West and Southern African countries (40% of African countries) fit in this cluster for maize. Cluster 5 is defined by a decrease of both yield and land area cultivated (e.g., Egypt, Eritrea, and Mauritania for maize).

4. Discussion

Agriculture is an important economic sector in Africa with a dependent population as high as 70–80% in some countries (Paul et al., 2018). On the continent, countries such as Ethiopia aim for agricultural development-led industrialization (Keulertz and Woertz, 2015). For the continent, agricultural land cover change is a critical factor in gauging agricultural production.

4.1. Understanding agricultural land change and drivers

Over the study period, grasslands, otherlands and wetlands decreased, whereas tree-covered areas, artificial surfaces, and croplands increased. Cropland and grassland losses are partly attributed to settlement expansion as in the peri-urban area of greater Cairo and Morocco (Creutzig, 2019; Salem et al., 2020). The urbanization axis along the West African coast is an African urbanization hotspot (Laurance et al., 2015) corresponding to areas of projected cropland loss due to settlement expansion (D'Amour et al., 2017). Thus, settlement development is a major driver of agricultural land loss in Africa. Cropland loss is also linked to afforestation as in Tanzania and the spontaneous regeneration of trees on abandoned croplands such as during conflicts as in northern Uganda, COD and Rwanda (Akinyemi, 2017). Rudel et al. (2020) noted the occurrence of regional forest transitions in the late twentieth century, whereby net reforestation replaces net deforestation, such as in the Sahel and East Africa. Considering that artificial surfaces are displacing agricultural lands, it is critical that spatial planning accounts for green infrastructure and agriculture as part of the urban landscape.

Relating these findings to land rent theories and land-use regulation (Meyfroidt et al., 2018), we argue that agricultural lands nearby settlements are being converted to housing and urban land-uses due to the

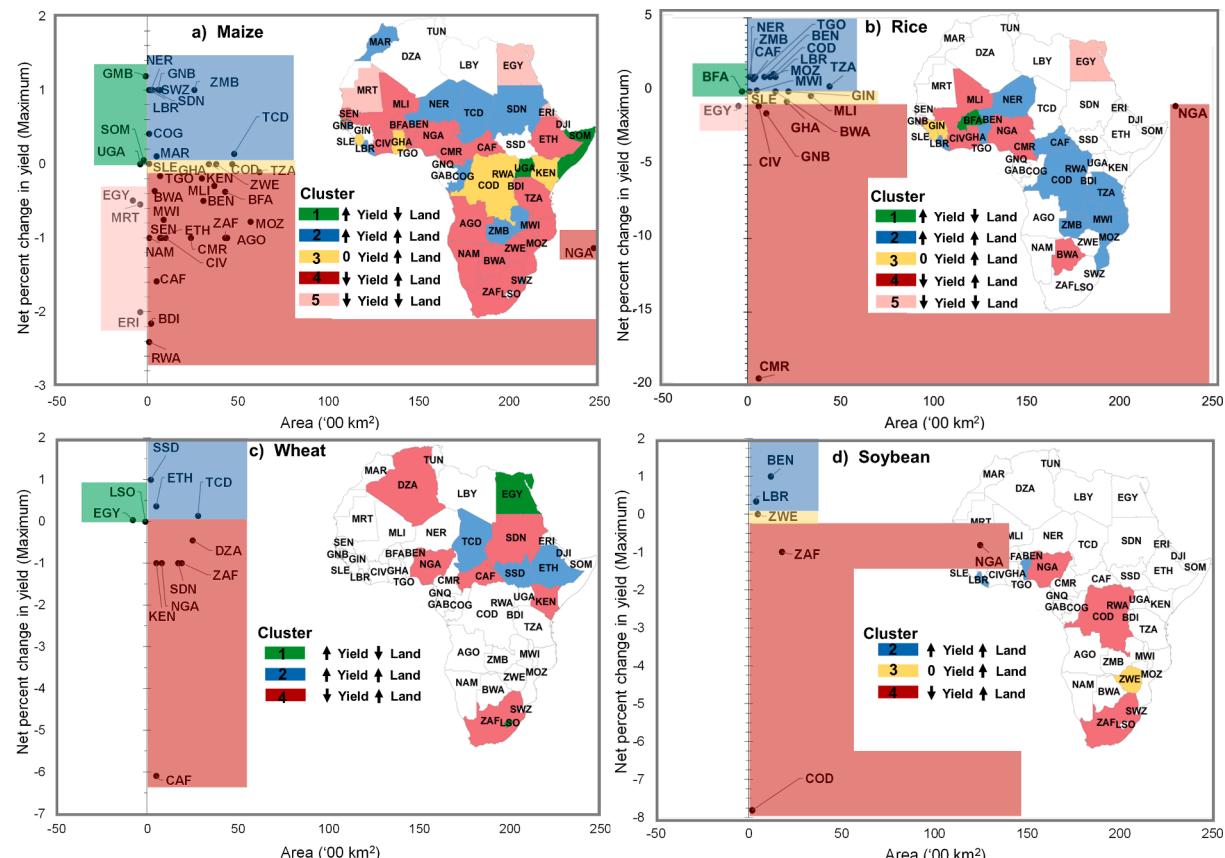


Fig. 6. Change in net percent crop yield and amount of land cultivated in gained and displaced croplands at the national level, a) Maize (clusters 1–5), b) Rice (clusters 1–5), c) Wheat (clusters 1, 2, 4), d) Soybean (clusters 2–4). ISO abbreviation for country names is used.

higher economic returns of these latter land-uses compared to agriculture. Settlements expand into nearby rural cultural and agricultural lands in response to the growing population's land demand for housing. Achieving sustainable agriculture in the affected regions in Africa thus calls, amongst other measures, for the protection of quality agricultural lands and culturally valued land by law to prevent their conversion to non-agricultural land-use. Depending on the contexts, the effects of such regulations can vary (Nixon and Newman, 2016; Li et al., 2019).

That croplands expanded at the expense of forests is confirmed in several countries. In COD, Turubanova et al. (2018) documented instances of primary forest loss to agriculture. In Uganda as in many parts of Africa, tree loss is attributed to livestock ranching and charcoal making (Kalema et al., 2015). Global drivers of land change are equally important in Africa (Keulertz and Woertz, 2015). For example, land area under export-crops increased in the Mount Kenya region in response to demand for horticultural produce in Europe (Ulrich, 2014), in Côte d'Ivoire and south-west Nigeria where primary forests were cleared for cultivating export crops (e.g. cocoa – *Theobroma cacao*, cassava – *Manihot esculenta*) (Abu et al., 2021; Akinyemi, 2013).

Grassland loss is attributed mainly to the expansion of artificial surfaces as in West Africa, croplands as in North Africa, Botswana, Zimbabwe and otherland (comprising mostly barelands) as in Mali and western Angola. In the Mediterranean coast of North Africa (e.g. Algeria, Morocco), cropland expansion into grasslands and otherlands (Molotoks et al., 2018) was possible through irrigation (Bouaroudj et al., 2019). Cropland expansion into grasslands such as in Southern Africa is also confirmed (Akinyemi et al., 2020). This transition was also found in Brazilian Amazonia, where pastures contributed 80% of new croplands in comparison to 20% of forests converted to cropland since 2000 (Zalles et al., 2019). Grassland gains were mainly from otherland as in Namibia and from cropland and tree-covered areas as in Kenya. For example, cropland degradation and drought informed farmers' decision to convert croplands to grassland for grazing in the Mount Kenya region (Zaehringer et al., 2018). Grassland conversion to otherland implies rangeland degradation as pastures deteriorate into barelands, otherwise shrub areas and otherlands alternate with grasslands, probably in response to rainfall variability and drought as found in the Sahel (United Nations Environment Programme, 2012).

Factors driving agricultural land dynamics in Africa include the distance of agricultural lands to settlements and proximity to major roads. Proximity to perennial rivers/water bodies was also important as in Egypt's Nile Delta where urban expansion is mostly at the expense of croplands (D'Amour et al., 2017). That otherlands such as barelands are being converted into croplands in this region, proved the irrigation potentials and provided an answer about where croplands are expanding in the region. In West Africa as in other parts of Africa, projected cropland loss due to urban expansion (D'Amour et al., 2017) has implications for conserving tropical forests in the region (Curtis et al., 2018). We found that the majority of areas of cropland gain were associated with large distances away from major roads. This result of cropland gaining lands with poor major road access suggest likely cropland expansion into remote forests. This finding is confirmed as African smallholder farmers' confrontation of an uncertain production environment is compounded by enormous physical accessibility constraints to markets and huge transportation costs as farms are typically distant (FAO, 2002). Access to major roads will prove even more important as a driver of ALC in the future because African governments are promoting development corridors to improve transboundary transportation and economic development (Laurance et al., 2015).

4.2. Relating agricultural land change to land quality

Areas gained by cropland were generally of better quality than in areas of cropland displacement. The former had the highest mean NPP and positive change in NPP. However, NPP trends differed between regions in areas gained by croplands. Decreased NPP trends in the

Guineo-Congo and Congo Basin rainforests relate more to forest conversion to cropland (Devaraju et al., 2015), whereas increased trends in the Sahel to re-greening (Dardel et al., 2014). Exchanges in north and southern Africa were mostly between cropland, grassland and otherland and relate more to rainfall variability. Extensive cropland expansion into lands of medium suitability in the Guinean Savannah is confirmed by Creutzig et al. (2019). Maximum mean NPP was higher in grassland gain areas than in displaced grasslands. Most grassland gain areas in the lowest NPP quartiles are in the Sudan and Sahel savannahs. This partly explains why croplands gained from grasslands and otherlands had decreased NPP. However, Devaraju et al. (2015) noted higher terrestrial NPP estimates for grasslands than croplands in the tropics.

SOC is generally low in African soils and areas with adequate soil quality are needed for food production. We relate SOC to ALC because cultivation for example, necessitating the clearing of native vegetation, affects soils. Gained croplands had higher SOC content than displaced croplands, whereas the opposite was obtained for grasslands. These imply that croplands gained more productive lands, whereas more productive grasslands were lost. Findings are in line with existing evidence such as cropland expansion negatively affecting land carbon stock with Africa having the highest projected carbon loss due to cropland expansion (Molotoks et al., 2018; Creutzig et al., 2019).

Regarding land quality in areas of agricultural land change, we examined land suitability for cultivating maize, rice, wheat, soybean and alfalfa. Five clusters derived based on the relationship between yield and amount of cultivated land were characterized by differing degrees of agricultural intensification and extensification. The Guinea savannah of West Africa and the East African coastal forests are hotspots of cropland expansion in Africa (Molotoks et al., 2018; Creutzig et al., 2019). Despite increasing net cultivated land area, most countries, especially in sub-Saharan Africa, had decreasing net yield for all four food crops. High yield gaps in these countries are largely due to land degradation, limited farm inputs, poor public infrastructure, civil conflicts and drought impacts on rainfed agriculture (Hillocks, 2014). Countries such as The Gambia had increased net percent change in maize yield with decreased land under maize cultivation, same for rice in Burkina Faso, and wheat in Egypt and Eswatini; Zambia and Niger increased net yields of maize and rice while increasing cultivated land. Cropland expansion in Zambia is confirmed for maize, and Zambia is now a maize exporter (Braimoh et al., 2018). The finding that net change in crop yield remained low or even decreased in some instances despite increased cultivated land is to be interpreted with caution due to discrepancy in the period covered by the ALC analysis (2000–2018) and crop yield data (1989–2008). Although values are not to be interpreted as absolute, net percent change was best at detecting the direction of change in crop yield and cultivated land area in each country. This served the purpose of our analysis well, which was to examine how land quality differed in agricultural change areas. The typologies of countries based on net yield and amount of land cultivated for a certain crop in cropland change areas contribute to the current debate on sustainable intensification of agriculture in Africa (Jayne et al., 2014).

Our findings hint at the remoteness of the majority of lands gained by cropland. This highlights the need to better understand how lost agricultural lands are compensated for. We argue that displacing productive agricultural lands motivates farmers to move elsewhere to farm. Kopper and Jayne (2019) examined the Boserupian agricultural intensification patterns in Kenya. They note that farmers in areas with good access, i.e., market and road access, have greater incentives to use land-saving practices. As croplands gained mostly at the expense of forests, linking our finding to the clearing of forests, especially primary forests, may largely explain the better quality of gained croplands and the dominance of cropland extensification across Africa.

5. Conclusion

We assessed agricultural land change (ALC) in continental Africa

(2000–2018). ALC relates to how agricultural lands, i.e., croplands and grasslands, have changed to other uses whereby agriculture has been ‘pushed out’ (i.e., lost croplands and grasslands), and land uses agriculture has ‘taken over’ (i.e., gained croplands and grasslands). We considered land-uses to which agricultural lands are transitioning, factors driving ALC and land quality in displaced and gained agricultural lands. We analyzed land change for seven land cover categories from which we identified major land transitions to and from agriculture. As settlements are expanding at the expense of mostly croplands across Africa, and croplands are expanding into forests and grasslands, there is the need to protect productive croplands and grasslands from transitioning to croplands or otherlands. Access to major roads, distance to settlements, proximity to perennial river/waterbody and elevation were important for explaining ALC in Africa. That the accessibility dimension, measured as proximity to major roads, had a positive influence on cropland loss and negative influence on cropland gain suggests that proximity to major roads promotes the loss of croplands, whereas newly gained croplands are less accessible. Future analysis of the temporal progression within shorter periods (e.g., annual or the use of several time intervals within a study period) can confirm whether newer croplands are rather farther away from major roads than earlier established. Also, in assessing the distance to major roads in agricultural land change areas, no differentiation was made between agricultural lands used for producing food crops and export crops.

Land quality indicators in ALC areas are NPP as a proxy for the availability of natural resources, SOC for soil health, crop suitability and yield for five crops of global importance which are produced and consumed across Africa (i.e., maize, wheat, rice, soybean and alfalfa). All indicators except NPP trends confirm that in most African countries, gained croplands were of better quality than those lost. In comparison to areas of cropland loss, cropland gain areas had higher NPP mean, SOC content, high to moderate crop suitability index, and increased percent change in crop yield. Conversion of forests and grasslands into croplands may have decreased NPP trends. For example, decrease in NPP is to be expected in areas of cropland gain if such gains were made from forests or other high productivity land uses. For grassland, lost areas were of better quality than gained. That grasslands were mostly converted to croplands, imply that marginal lands are being cultivated with the need for more farm inputs. For each of the four major crops examined, African countries were associated with one of five clusters characterized by differing degrees of cropland intensification or extensification. Despite the net increase in cultivated land area, i.e., cropland expanded in many countries, the net change in crop yield remained low or decreased in some instances. How ALC may affect agricultural production was implied in the analyses, but caution is required in interpreting results due to the discrepancy in the analysis period (2000–2018 for ALC, 1989–2008 for crop yield). Further research into ALC interactions with agricultural productivity is hampered by the lack of current yield data in rainfed and irrigated systems, including those of livestock farming.

We provide generalizable insights about land quality in areas of agricultural change across Africa. While the focus on the African continent enabled delving deeper into the Africa-specific implications of such land changes than global studies do, future studies need to examine the quality of land in areas of land-use persistence as this study was limited to areas of land change. Going forward, exploring, and developing insights about the implications of land system change for food security are required for Africa. The possibility of having comparable, longer-term land cover time-series datasets across Africa at higher spatial resolution from Sentinel in the coming years, will further improve results derived from studies such as ours.

CRediT authorship contribution statement

Felicia O. Akinyemi: Conceptualization, Methodology, Analysis, Writing - original draft, Visualization. **Chinwe Ifejika Speranza:** Conceptualization, Methodology, Writing – edit.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jag.2021.102644>.

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