Original Research Article

Land use dynamic and soil fertility in the Orodara municipality, Burkina Faso

Abstract

To respond to the degradation of natural resources and the installation of an imbalance between production and consumption needs, the populations of Orodara have adopted an association of fruit arboriculture and cereal growing on the same plot. These changes have favoured the development of a specific agrarian landscape of the fruit agroforestry type. This study questions the evolution of soil fertility in the face of land use dynamics in Orodara. The exploitation of Landsat satellite images of multi-dates (1991 to 2018) made it possible to obtain information on land use. Fertility data were obtained from the analysis of the organic matter, the sum of exchangeable bases as well as the hydrogen potential (pH) of soils from 1997 to 2019. The analysis of our results shows a production system dominated by fruit growing in association with cereal growing. Two units of agricultural occupation were divided in 1991 between annual crops (56%) and permanent crops (4%). Between 2002 and 2018, a third unit developed from the association of the first two, occupying 39% of the total area in 2018, compared to 19 and 13% respectively occupied by annual and permanent crops. This dynamic affects the evolution of soil fertility. From 1997 to 2019, fertility decreased by 23% from the average rate and increased by 22% from the low fertility rate. Contrary to the increase in vegetation cover, the level of soil fertility declines, compromising the sustainability of agricultural production in the municipality of Orodara.

Keywords: Fruit tree growing, cereal growing, soil fertility, Orodara, Burkina Faso.

1. Introduction

In Africa and particularly in Burkina Faso, producers are faced with declining soil quality, climate variation, and severe land degradation. All these elements contribute to the extension of sown areas with a reduction of forests in favor of anthropic areas. In addition, in Burkina Faso, more than half of the land is poor in organic matter, 85% is very poor in phosphorus, and 61% is very poor in nitrogen; It is also noted that the quantitative loss of soil due to water and wind erosion can reach 1000 to 2000 t/year[1]–[4].

The availability of cropland, which varies from one region to another, is related to ecological conditions. The quality of the soil and the uneven distribution of rainfall are responsible for very different agroecological situations depending on the region. Western Burkina Faso is particularly renowned for its cotton production. This culture has revolutionized all agricultural systems by moving from a largely dominant culture to a more diversified agriculture [5]. According to [6], if the bush (natural vegetation) was still available and diversified in the 1956s, then it would have subsequently experienced a strong regression in favor of fields and orchards. However, faced with the decline in production, the populations have, alone or with the support of technical and financial resources from the State, projects, and NGOs, undertaken water and soil conservation works as well as agroforestry. In recent years, the concept of "Conservation Agriculture" has emerged as a strategy[1], [4], [7], [8].

The current dynamics of spatial change in land cover is related to the practice of arboriculture associated with cereal cultivation in western Burkina Faso, particularly in the Orodara municipality. This municipality is under the influence of agricultural pressure through an increase in anthropogenic formations to the detriment of natural ones; thus 25,443.01 ha of the area were exploited in 1992, compared to 29,153.57 ha in 2002 and 30,165.85 ha in 2014[9]. This decrease is not without consequences on natural resources, especially when exploitation or use is continuous and without the practice of fallowing.

The degradation of natural resources affects water and vegetation as well as soil and air. The literature indicates that several studies have focused on the decline in soil fertility as well as on the change in agricultural practices and land use[2], [10]–[12]. However, very little research makes the link between the evolution of soil fertility and the dynamics of land use. From this observation, we can ask ourselves, what is the impact of the dynamics of land use of fruit arboriculture on the soil fertility in the Orodara municipality? The objective of this studyis to analyse the evolution of soil fertility under the cultivation of fruit trees in Orodara, in western Burkina Faso.

2. Materials and methods

2.1.Presentation of the study site

The Orodara municipality (capital of the province of Kénédougou, HautsBassins region) is the study site chosen for this research. Covering an area of 410 km² (map n°1), it is located in the far west of Burkina Faso, 440 km from Ouagadougou, 75 km from Bobo-Dioulasso, and 100 km from Sikasso in Mali.

Located on a sandstone plateau, the communal landscape is very uneven and dominated by glacis on which agriculture is practiced. The arrangement of crops is made according to geomorphological units: mango plantations occur in low areas and on glacis with lower and medium slopes; those cashew trees are placed on the slopes, the glacis middle and upper slopes[9]

The study area straddles two watersheds: that of the upper Mouhoun located in the North and East and the upper Comoé basin occupying the southern and western part. With a climate of the South Sudanese type, it benefits from an average rainfall of more than 1000 mm/year. Almost all (98%) of the area rests on geological support of a sedimentary nature, the preferred support, weakly desaturated ferralitic soils typical modal (dftm), 60% of the total area. Due to their depth, these soils have characteristics suitable for the production of fruit trees. Three plant formation units are essentially distinguished, belonging to the western district of Mouhoun in the Sudanese domain. These are savannas, gallery forests, and agroforestry parks.

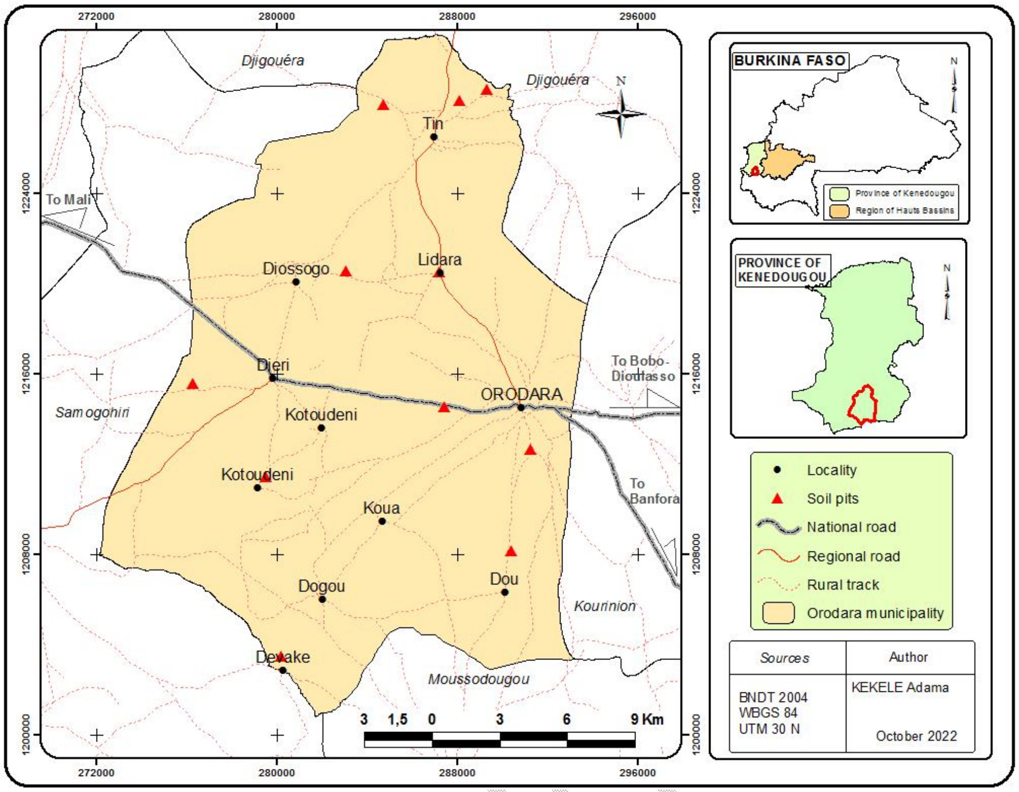


Fig. 1.Municipality of Orodara situation

2.2.Methods

Several approaches have been used in order to take into account the maximum analysis criteria of the dynamics of land use and the evolution of soil fertility, namely: the systemic approach andthe spatio-temporal approach. The FAO land evaluation method[13], adapted to the agro-ecological conditions of Burkina Faso, was used to evaluate soil fertility in the Orodara municipality.

The choice of Landsat images (30 m resolution)to carry out a diachronic study was essential. The periods (February to May) retained in the context of this work are those where the contrast was high with fewer cloud disturbances, allowing a fairly good discrimination of the occupation units. The dates of the selected images related to the periods of 1991, 2002, and 2018. The classification was usually made on multi-spectral databases. This process gave each pixel of an image a certain class or theme based on the statistical characteristics of the pixel's intensity value[14]. For this research, the choice was focused on supervised classification; because it is much more advantageous.Combined with knowledge of the field, it made it possible to reason out the choice of training sites and facilitate image processing.

Furthermore, concerning the characterization of soil types in the study area, 11 soil pits were opened on the site or near the old pits made by BUNASOLS(National Office of the Soils) in 1997. These pits were described according to FAO guidelines (2006). Colours were assessed using the Munsell Code (2009). Textural classes were appreciated in the field in a tactile way. Sampling was also carried out in 2019, on the epipedon horizon of the upper 30 cm of the ground for each pit described. Also, a summary description of the soils was made at the sampling sites on sheets prepared for this purpose (surface conditions, type of use or occupation, geomorphological unit, plant cover, etc.). The soils have been classified according to the Commission de

Pédologieetde Cartographie des Sols (CPCS of 1967) and the World Reference Base of soil resources (WRB of 2015).

2.3.Materials

Several tools were used in data collection and analysis. These are essentially applications (software), Munsell code, field data collection sheets as well as a GPS and a camera. The ENVI 4.8 software was used to stack the different bands (Layer stacking) necessary to display the images in colored composition 743 from Landsat 8 OLI, 7 ETM, and 5 TM as well as a composition 542 from Landsat MSS 5. It is from this stacking of bands and thanks to the available algorithms that various treatments were carried out. Mainly, the realization of the various maps was made with ArcMap of the ArcGIS 10.4 software. As for the land use data resulting from the image processing, they were groomed with the same application in order to harmonize the topology, correct the imperfections and generate the areas of all the surface units.

3. Results

The exploitation of natural areas by man induces changes in both plant cover and soil fertility. The use of multi-date images made it possible to analyze the dynamics of land use and the manipulation of soil chemical parameters made it possible to generate soil fertility for 1997 and 2019.

3.1.Evolution of land use in the municipality of Orodara

Three land cover maps were produced with data obtained from the interpretation of Landsat images from 1991, 2002, and 2018 (30 m resolution). Seven major units identified are grouped into two formations:

- natural formations composed mainly of gallery forest, wooded and shrubby savannas;
- anthropogenic formations made up of artificial water bodies, habitats, and areas of permanent crops, associated crops, and annual crops. Are considered as permanent crops, all orchards, and forest plantations; as annual crops, these are all fields of cereals, rainfed rice and all other rainfed crops (cotton, peanuts, sesame, etc.); and for associated crops, these are all forms of association of permanent, and annual crops.

The confusion matrix gave an overall precision of 80% and a Kappa coefficient of 0.76 (Table 1). This reflects a perfect quality of image interpretation. Also, the types of occupation obtained better accuracy rates (>64%) (Table 1).

Table 1. Confusion matrix of the interpretation of the Landsat OLI8 image of 2018

Overall accuracy									80.08 %	
Kappa Coefficient									0.76	
Field reference	**Wb**	**Gf**	**SA**	**Sa**	**Anca**	**Assca**	**Perca**	**Total**	**UP (%)**	**CE (%)**
Water body (Wb)	100							100	100	0
Gallery forest (Gf)		98					18	116	69,6	30,4
Wooded savanna (Ws)		2	70	4	3	9		87	58,6	41,4
Shrubby savanna (Shs)				77				77	99,9	0,1
Annual crops area (Anca)				19	64			83	73,7	26,3
Associated crops area (Assca)			21		33	91		145	71,4	28,6
Permanent crops area (Perca)			9				82	91	95,2	4,8
Total	100	100	100	100	100	100	100			
PP (%)	99,6	98,3	70,0	76,8	63,9	90,7	81,7			
OE (%)	0,4	1,7	30,0	23,3	36,1	9,3	18,3			

UP: User Precision, PP: Producer Precision, CE: Commission Error and OE: Omission Error

The cross-analysis concerns land use data of the three dates (1991, 2002, and 2018) and for a question of harmonization, the habitat, and the areas of annual, associated and permanent crops have been grouped into a single unitof crops zone.

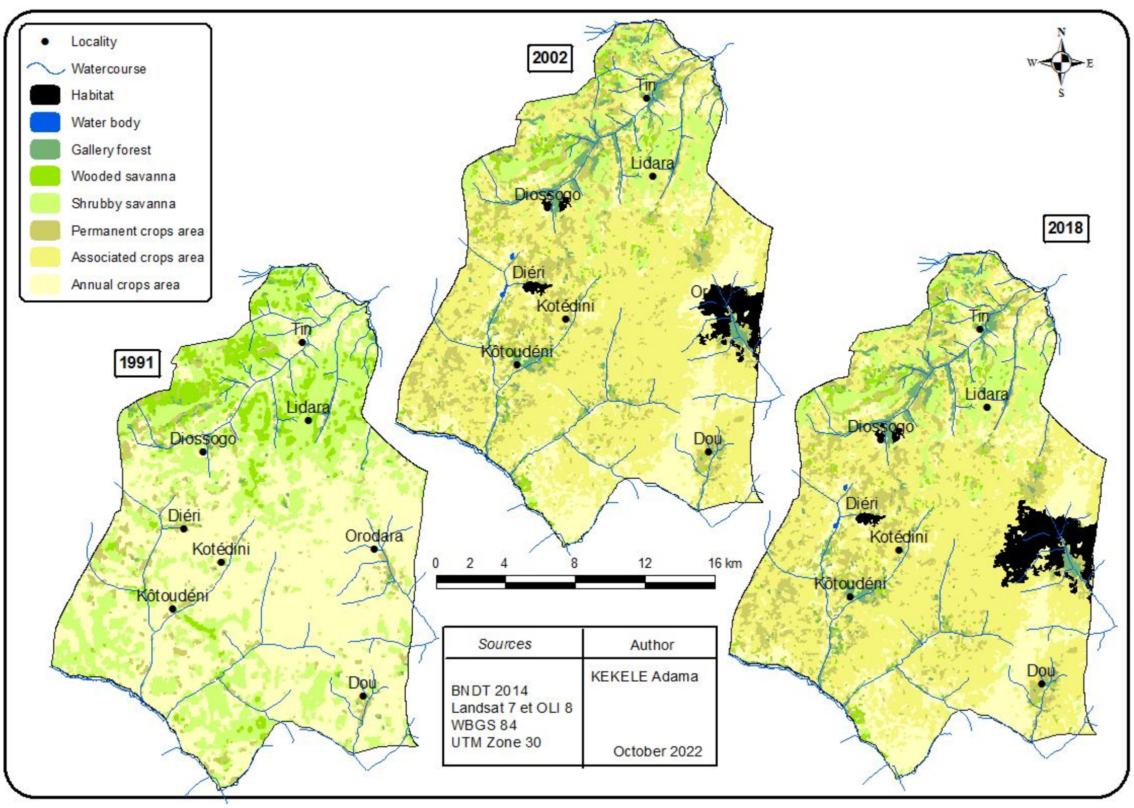


Fig. 2. Land use units of 1991, 2002, and 2018, in municipality of Orodara

3.1.1. Land use dynamics from 1991 to 2002

The change in land use units between 1991 and 2002 is summarized and noted in Table 2. It shows that the surface area of the 1991 cultivation zone changed very little in 2002 (53,94% preserved) but it mainly extended, occupying the savannas (20,76% shrubby savannas against 2,06% tree savannas) which, on the contrary, experienced a regression. The gallery forest is experiencing a progressive average rate (13%) of its extent with a change of 2,20% of the crops zone. This is explained by the fact that the lowlands and the edges of watercourses are more exploited for mango orchards (*Mangiferaindica*). Moreover, the little recovery for the savannas comes from the crops areas, through their fallowing, which has indeed been confused with the shrubby or wooded savannas, in relation to their age.

Table 2. Matrix of transition between 1991 and 2002

Units of 2002	Units of 1991				
	Gallery forest	Wooded savanna	Shrubbysavanna	crops zone	General total
Gallery forest	0,23	0,10	1,20	2,20	**3,73**
Wooded savanna	0,19	1,55	0,85	0,63	**3,22**
Shrubbysavanna	0,17	2,90	9,30	3,62	**15,98**
Crops zone	0,30	2,06	20,76	53,94	**77,06**
General total	**0,89**	**6,62**	**32,10**	**60,39**	**100,00**

Source: Land use data of 1991 and 2002

3.1.2. Land use dynamics from 2002 to 2018

The diachronic analysis of land use from 2002 to 2018 indicates a notable change in units as shown in Table 3. The transition matrix from 2002 to 2018 shows that more than 71,12% ofthe surface of the crops area remained unchanged in 2018 compared to 77,06% in 2002. Of this, more than 10,32% of the shrubby savanna changed into crop space and conversely, only 2,61% of the crop area was returned to shrubby savanna (Table 3). As for the wooded savanna and the gallery forest, they have changed a lot with respectively a loss of space for the first and a slight increase for the second unit.

Table 3. Matrix of transition between 2002 and 2018

Units fo 2018	Units of 2002				
	Gallery forest	Wooded savanna	Shrubby savanna	crops zone	General total
Gallery forest	1,68	0,44	0,42	1,52	**4,06**
Wooded savanna	0,08	0,31	0,58	1,81	**2,79**
Shrubby savanna	0,03	0,37	4,66	2,61	**7,68**
crops zone	1,93	2,10	10,32	71,12	**85,48**
General total	**3,73**	**3,22**	**15,98**	**77,06**	**100,00**

Source: Land use data of 2002 and 2018

3.1.3. Land use dynamics from 1991 to 2018

The cross-analysis of the table (4) explains the progression of the crops area (1.30%) by the fact that nearly 56,34% of this unit in 2018 representing 60,39% of the area ofthe municipality in 1991 remained static in 27 years of cultivation. On the other hand, it (the crops area) has expanded by monopolizing about 29% of the surface area of natural formations, 23,90% of which comes from the shrubby savanna. All of this explains the strong annual regression of this shrubby savanna of -5,30%. The wooded savanna is not spared from anthropogenic pressure since 4,74% of its area is exploited.

Table 4. Matrix of transition between 1991 and 2018

Units of 2018	Units of 1991				
	Gallery forest	Wooded savanna	Shrubby savanna	crops zone	General total
Gallery forest	0,29	0,52	1,12	2,14	**4,06**
Wooded savanna	0,06	0,59	0,88	1,26	**2,79**
Shrubby savanna	0,04	0,77	6,21	0,65	**7,68**
crops zone	0,50	4,74	23,90	56,34	**85,48**
General total	**0,89**	**6,62**	**32,10**	**60,39**	**100,00**

Source: Land use data of 1991 and 2018

3.2.Evolution of soil fertility in the Orodara municipality

Five elements were extracted from samples taken from each soil pit. These are basically the particle size of 5 fractions (clay, fine silt, coarse silt, fine sand, and coarse sand), total carbon (total organic matter), nitrogen, exchangeable bases and cation exchange capacity, and finally the water pH. This made it possible to use the minimum range to assess the fertility of the land through the summation of the organic matter, the sum of the exchangeable bases, and the water pH(table 5). The sum of the quotations was assessed according to the intervals of the classes suggested by [13]recorded in table 6 below.

Table 5. Sample analysis data

	1997			2019		
Pit	**OM total %**	**Sum of the exchangeable bases (S)méq/100g**	**Water pH**	**OM total (%)**	**sum of the exchangeable bases (S)méq/100g**	**Water pH**
BK175	0,97	2,02	5,1	0,5	1,38	5,47
BK194	0,53	0,77	5,23	0,5	0,97	5,34
BK206	0,78	1,84	5,05	1,5	3,83	4,97
BK209	1,08	2,47	5,24	0,81	1,79	5,2
BK234	2,04	4,42	4,96	0,38	1	5,07
KD138	0,56	1,77	5,45	0,45	0,92	4,68
KD147	0,92	1,89	5,56	0,5	1,12	5,6
KD203	0,45	1,35	5,32	0,5	0,98	5,79
KD216	0,7	1,05	5,65	1,5	1,28	5,81
CK212	0,6	1,36	5,29	0,81	1,05	5,71
KD174	1,1	5,17	6,12	0,38	1,08	5,28

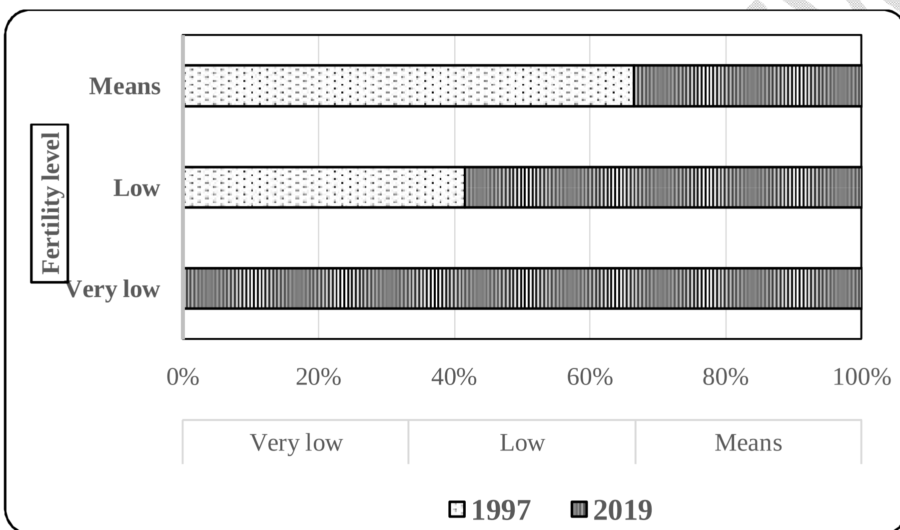
Table 6. Suggested intervals of fertility classes

Class	Very low	Low	Average	High	Very high
Sum of the quotations	< 4,4	4,5 – 7,5	7,6 – 10,5	10,6 – 13,5	> 13,6

Source: BUNASOLS, 1990

The analysis of the evolution of fertility highlights a spatiotemporal variation in the level of soil fertility in the Orodara municipality. The cross-referencing of spatial data (fig. 3) of the two dates

(1997 and 2019) made it possible to assess this evolution. In 12 years of exploitation, the soils have experienced a fluctuation in the level of their fertile quality. Indeed, in 1997, the levels were between low and average, but in 2019, in addition to varying between low and average, they have evolved to a third, very low. This means that the level of fertility has dropped in the Orodara municipality. In addition, 56% of the surface area of crops areas remained in operation for 27 years. This explains the reduction in the average level of fertility by 23% (in 2019) against 47% (in 1997) in favour of the low level, which also extended from 53% (in 1997) to more than 75% (in 2019). The overall level of soil fertility has thus evolved downwards between the two dates, with the appearance to the south of the town of Orodara of a very low level of fertility, representing 1% of the municipal area. This situation further supports the idea of fertility regression or deterioration. The areas with average fertility status in 2019 can be summed up in small isolated portions distributed on fig. 5, unlike the situation in 1997, where they were more uniformly continuous.



Source: Soil fertility data of 1997 and 2019 KEKELE A.

Fig. 3. Evolution of soil fertility from 1997 to 2019

By comparing this evolution of soil fertility with that of land use, it emerges that despite the strong association of fruit trees with cereal crops, which makes it possible to maintain (in another form) the trees in the fields, the soil quality does not experience a positive evolution. This raises questions about the sustainability of this association as an issue of agricultural production in the municipality in general and in certain locality in particular. At what level is the problem in this production system?However, some raising points are visible on the maps and especially in the locality of Lidara. This is due to fallowing with a fairly heavy cover of surface litter (fig. 4).

Fig. 4. (Plate by KEKELE. May 2019): Soil surface covered by litter

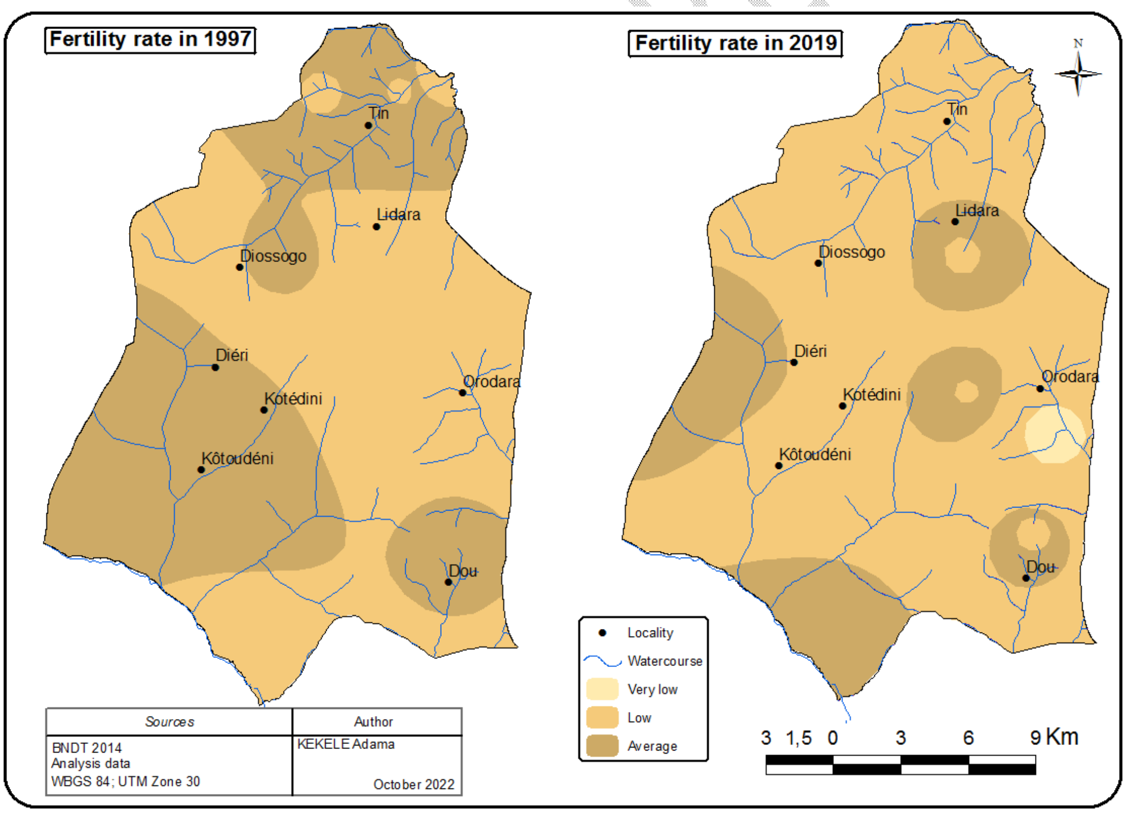


Fig. 5. Evolution of soil fertility in the municipality of Orodara between 1997 and 2019

4. Discussion

4.1. Land use dynamics

Numerous studies in Burkina Faso and in other West African countries have underlined the transformation of natural formations to the detriment of anthropic spaces, through work carried out on the change of land use[2], [6], [9], [15]–[18].For example,[17] present a regression of natural formations in favour of anthropogenic formations in western Burkina Faso in the face of agricultural migration.[19]also drew attention to the land problem in the area and particularly in the Kouka municipality, based on the analysis of a series of land uses, which shows the saturation of formerly open space. Like the west, other parts of the country are not on the side-lines of this development. [15], based on a multi-date analysis (1984 and 2015) of land cover and vegetation trend assessment, estimated the dynamics of the vegetation cover on the periphery of park W, located in the east of Burkina Faso.[20] and [16], through a confrontation between climatic variability and the use of space by agro-pastoralists, find a mutation in agricultural and livestock practices and an evolution in land use between 2002, 2010, and 2018 in the country's Sahel.

The main cause of this conversion of units is essentially linked to the growth of the population, which is highly dependent on its environment. Western Burkina Faso has experienced a migratory movement over the past 30 years. This migratory dynamic is mainly linked to the boom in cotton production and the movement of agricultural colonization, with the occupation of lowlands and plains as a strategy for adapting to climate change. Indeed, human pressure is exerted on the plant cover through agricultural practices and logging. This is confirmed by studies by[19] and [17], who point out that agricultural migration to the west of the country has greatly contributed to the degradation of natural vegetation. The role of this anthropogenic pressure on the evolution of the vegetation cover is characterized by several authors.For[19], the extension of the areas of crops areas as a solution to the increase in the number of the population has reached its limits (83% of the area of the Orodara municipality is exploited), but the population continues to grow despite the lack of land to clear. As a result, producers develop strategies to better exploit their agricultural spaces through an association of crops in the municipality of Orodara.

Agroforestry is the most dominant production system in the municipality of Orodara. The increase in crops areas is partly explained by the adoption of the cultivation of fruit trees by the population of western Burkina Faso. This observation was made by[6], [9], [21], [22]. The growth in the area of crops areas is linked to the rapid expansion of fruit growing and annual crops. For[22], the extension of orchards has been massive and rapid, because of 1000 ha of orchards of the “Cashew” project in 1980. Burkina Faso now has more than 80,000 ha of orchards.[6], as well as [9]also found that the cultivated area consisted of large family orchards of mango, cashew, and citrus trees.

4.2. Soil fertility dynamics

The influence of agricultural practices on soil fertility has been observed and described by several authors through their research on soil fertility, soil erosion or degradation, land use, management systems or methods. restoration of soil fertility, etc.[2], [4], [23]–[29]. For this reason, the soils of the country are subject to all forms of pressure, both climatic and anthropogenic.

[25]found that in Burkina Faso, the soils are subject to all forms of pressure: abusive methods of exploitation, accelerated population growth, and land capital in continual degradation jeopardizing production systems.[30], from the analysis of the hydrodynamic properties of the soils in Burkina Faso, concluded that on the whole, the soils of the country have a low level of content of fertilizing elements, in particular phosphorus and nitrogen. This supports the continued decline in soil fertility in the municipality. For example, Baumer (1987 in[31]estimated that more than 50% of land is poor in organic matter, 85% in phosphorus and 61% in nitrogen. To deepen

understanding of soil parameter linkages,[32] investigated the edaphic component and established relationships between organic matter and the physical, chemical and biological properties of soils. From their results, it should be noted that the total carbon and nitrogen contents of the soils considered are low and comparable to those of the soils of the Sahelian region, in short, low organic matter for both ferruginous soils and ferralitic soils. All of this confirms the results of this current study which shows a general decline in soil fertility generated by the decrease in MO and the increase in hydrogen potential (pH) in the municipality of Orodara. Indeed, the practice of bush-fires and the burning of dry leaves, especially around fields without returning the ashes to the production area, contribute to the decline in soil fertility [33]. It is therefore necessary to review agricultural practices for the conservation of biomass in production areas in order to facilitate the restoration of fertility.

Moreover, [25] concluded that the decline in soil fertility seemed to be somewhat neglected among the induced effects of desertification. Soil degradation, and in particular the decline in soil chemical fertility, is a major concern with regard to food production and the sustainable management of land resources [2]. Indeed, how the crop-tree-soil interaction, both above and below ground, affects the productivity of specific agroforestry systems is not yet well understood and there are still important gaps to be filled in this area[7]. Few authors like[26] and [12] were respectively able to demonstrate, through the analysis of soil nutrient dynamics in cashew fields in Nigeria and the assessment of the variation of soil properties with landscape attributes in Cameroon, that soil properties soil are influenced by multiple physical and biochemical interactions driven by human activities and the biophysical characteristics of the landscape, including land use types and topographic positions. Also, while affecting land use to demographic change, the spatiotemporal change in soil fertility in interaction with the dynamics of land use remains little explored, and more research is needed investigations according to[2].

5. Recommendations

The distinction of the different land use units and the level of soil fertility makes it possible to coordinate thesoil restoration/conservation techniques, for a good distribution of actions on the ground. Thus, it is more recommended to leave in fallow the soils with very low fertility and exploited in agriculture.

6. Conclusion

Natural formations, occupying only 17% of the area in 2018, constituted the majority unit in 1972. But from 1991, the human imprint was felt with the cropping areas which became more dominant in time. 27 years of exploitation of 56% of the surface of the municipality without rest, cannot be without effect on the evolution of soil fertility and on the state of land degradation. The exploitation of land for the practice of agriculture has disturbed the level of most of the chemical parameters of the soil of the study area. Between 1997 and 2019, a drop in the rate of organic matter (OM) and the sum of exchangeable bases (SB) in the soil was recorded. In a logic of deterioration, these drops have made the soil much more acidic ($pH < 6$). The estimate made of the fertility, by the summation of these three elements (MO, SB, pH), naturally demonstrates a reduction in the quality of the soils of the Orodara municipality.

Bibliographicreferences

[1] C.E. D. Da, ‘Impact of water and soil conservation techniques on sorghum yield in north-central Burkina Faso’, Les Cahiers d’Outre-Mer. Geographical review of Bordeaux, vol. 61, no. 241–242, pp. 99–110, Jan. 2008, doi: 10.4000/com.3512.

[2] A. E. Hartemink, ‘Land use change in the tropics and its effect on soil fertility’, pp. 55–58, 2010.

[3] S. Nacro, S. Ouedraogo, K. Traore, E. Sankara, C. Kabore, and B. Ouattara, 'Comparative effects of peasant practices and good agricultural practices for soil fertility management on the properties of soils and crop yields in the southern Sudanian zone of Burkina Faso', International Journal of Biological and chemical sciences, vol. 4, no. 4, 2010.

[4] B. A. Bationo, A. Kalinganiré, and J. Bayala, 'Timber potentials in the practice of conservation agriculture in the arid and semi-arid zones of West Africa: Overview of some candidate systems' , Nairobi, Kenya, Technical Manual 17, 2012.

[5] V. Hauchart, ‘Cotton cultivation and soils degradation in Mouhoun (Burkina Faso)’, Geography, Reims-champagne-Ardenne, France, 2005. Accessed: Feb. 20, 2016. [Online]. Available: http://www.univ-reims.fr/site/laboratoire-labellise/groupe-d-etude-sur-les-geomateriaux-et-environnements-naturels-anthropiques-et-archeologiques-ea3795/theses-et- hdr/gallery_files/site/1/1697/3184/4013/39835.pdf

[6] A. Bene and A. Fournier, ‘Natural vegetation and land use in Burkina Faso (West Africa). Five decades of change in a terroir of the Sèmè country, in Crossed scientific perspectives on global change and development - Language, environment, culture, Ouagadougou, Burkina Faso, 2012, pp. 143–164.

[7] J. M. Boffa, ‘Agroforestry parklands in West Africa: keys of the conservation and sustainable management’, Unasylva, vol. 51, no. 200, p. 11–17, 2000.

[8] H. J. Geist and E. F. Lambin, ‘Dynamic causal patterns of desertification’, Bioscience, vol. 54, no. 9, p. 817–829, 2004.

[9] A. Kékélé, ‘Dynamics of rural landscapes and production system in the municipality of Orodara (western Burkina Faso) The association of fruit growing and cereal growing’, Master’s thesis, Paris1 Panthéon-Sorbonne, France, 2015.

[10] B. A. Drewniak, U. Mishra, J. Song, J. Prell, and V. R. Kotamarthi, ‘Modeling the impact of agricultural land use and management on US carbon budgets’, Biogeosciences, vol. 12, no. 7, p. 2119–2129, Apr. 2015, doi: 10.5194/bg-12-2119-2015.

[11] K. Sanou and B. A. Soule, ‘Constraints to the adoption of soil fertility management technologies in irrigated rice farming in South ofTogo’, African Agronomy, vol. 29, no. 2, p. 177–184, 2017.

[12] B. Takoutsing, J. C. Weber, J. A. Rodríguez Martín, K. Shepherd, E. Aynekulu, and A. Sila, 'An assessment of the variation of soil properties with landscape attributes in the highlands of Cameroon', Land Degrad Dev, flight. 29, no. 8, p. 10, Aug. 2018, doi: 10.1002/ldr.3075.

[13] BUNASOLS, ‘Manual for Land Evaluation’, National Soil Office, Ouagadougou, Burkina Faso, Technical Documentations 6, 1990.

[14] CCT, Basic notions of remote sensing. Canada, 2015. Accessed: Aug. 04, 2020. [Online]. Available: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/resource/tutor/fundam/pdf/fundamentals_e.pdf

[15] R. Gansaonré, ‘Vegetation cover dynamics and socio-environmental implications on the outskirts of the W/Burkina Faso park’, vertigo, vol. 18, no. 1, 2018, Accessed: Feb. 15, 2021. [Online]. Available: https://www.erudit.org/en/journals/vertigo/1900-v1-n1-vertigo04481/1058441ar/abstract/

[16] B. Ouédraogo, O. Kanboré, M. M. Dama-balima, and R. N. Gansaonre, 'Climate variability and land use in the watershed of the Yakouta dam (Sahel Burkinabè)', International Journal of Innovation and Scientific Research, vol . 46, no. 1, p. 25–38, 2020.

[17] F. Sanogo, A. Kékélé, and D. E. C. Da, 'Agricultural migration and dynamics of land cover in the '"Plandi 2" sub-watershed of Upper Mouhoun, Burkina Faso', Revue des Langues, Lettres et Sciences de l’Homme et de la Société, vol. 2, no. 9, p. 391–408, 2020.

[18] K. Adjonou, I. A.-K. Bindaoudou, R. Idohou, V. Salako, R. Glele-Kakaï, and K. Kokou, 'Satellite monitoring of the spatio-temporal dynamics of land usein the Mono

transboundary biosphere reserve between Togo and Benin from 1986 to 2015', in OSFACO Conference: Satellite images for the sustainable management of territories in Africa, Cotonou, Benin, 2019, p. 24.

[19] L. Paré and B. Tallet, ‘From an open space to a saturated space. Land and demographic dynamics in the department of Kouka (Burkina Faso)’, espos, vol. 17, no. 1, p. 83–92, 1999, doi:10.3406/espos.1999.1871.

[20] P. A. Ouoba, ‘Vegetation dynamics in Kékénéné in the Burkinabe Sahel’, Environmental Sciences, University of Lome, Togo, vol. 10, no. 2, p. 187–206, 2013.

[21] S. Audouin, ‘Innovation systems and territories: a game of interactions. The examples of cashew and jatropha in the south-west of Burkina Faso’, Doctoral thesis, University Panthéon-Sorbonne-Paris I; International Institute of Engineering, Paris, France, 2014.

[22] S. Audouin and A. Gonin, ‘Cashews: product of globalization, driving force of territorialisation, the example of southern Burkina Faso’, echogeo, no. 29, p. 13, Nov. 2014, doi: 10.4000/echogeo.13926.

[23] M. Mazour and E. Roose, 'Influence of land cover on stream and soil erosion on erosion plots in the watersheds of North-West Algeria', Bull Réseau Erosion, vol. 21, p. 320–330, 2002.

[24] N. A. Somé, K. Traoré, O. Traoré, and M. Tassembedo, ‘Potential of artificial fallows in Andropogon spp. in improving the chemical and biological properties of soils in the Sudanian zone (Burkina Faso)’, Biotechnol. Agron. Soc. Approx., vol. 3, no. 11, p. 245–252, Jan. 2007.

[25] C.E. D. Da, H. Yacouba, and S. Yonkeu, ‘Morphopedological units and soil fertility management in north-central of Burkina Faso by local populations’, International Journal of Biological and Chemical Sciences, vol. 2, no. 3, p. 306–315, Oct. 2008, doi: 10.4314/ijbcs.v2i3.39746.

[26] P. E. Aikpokpodion, B. Uloko, and G. Edibo, ‘Nutrient dynamics in soil and cashew (Anacardium occidental L.) leaf and kernel in Kogi State, Nigeria’, Journal of Applied Biosciences, vol. 25, p. 1573–1578, 2009.

[27] J. T. Yaméogo, A. N. Somé, A. Mette Lykke, M. Hien, and H. B. Nacro, 'Restoration of the potentialities of degraded soils using zaï and stone bunds in western Burkina Faso.', Tropicultura , flight. 31, no. 4, 2013.

[28] P. D. Kombienou, O. Arouna, A. H. Azontondé, G. A. Mensah, and B. A. Sinsin, 'Characterization of the soil fertility level of the Atakora range in northwestern Benin', Journal of Animal and Plant Sciences, flight. 25, no. 2, p. 3836–3856, 2015.

[29] R. Yonaba, 'Spatio-temporal dynamics of surface states and influence on stream in a Sahelian-type watershed: case of the Tougouwatershed (Northern Burkina Faso)', PhD Thesis, International Institute of Engineering 'Water and the Environment, Ouagadougou, Burkina Faso, 2020.

[30] Y. Dembele and L. Somé, 'Hydrodynamic properties of the main soil types in Burkina Faso', in Proceedings of the Niamey Workshop, February 1991) IAHS Publ, 1991, vol. 199, p. 217–227. Accessed: Dec. 29, 2016. [Online]. Available: http://hydrology.org/redbooks/a199/iahs_199_0217.pdf

[31] A. Bationo, B. Waswa, J. Kihara, I. Adolwa, B. Vanlauwe, and K. Saidou, Eds., Lessons learned from Long-term Soil Fertility Management Experiments in Africa. Dordrecht: Springer Netherlands, 2012. doi: 10.1007/978-94-007-2938-4.

[32] F. J. P. Pallo, N. Sawadogo, L. Sawadogo, M. P. Sedogo, and A. Assa, 'Status of soil organic matter in the southern Sudanese zone in Burkina Faso', Biotechnol. Agron. Soc. Approx., vol. 12, no. 3, p. 291–301, 2008.

[33] A. Fournier, M. Douanio, and A. Bene, 'Practice and perception of wildfires in an orchard landscape. Sèmè country (Kénédougou, Burkina Faso)', in Language, environment, culture: multidisciplinarity and development, Ouagadougou, Burkina Faso, 2014, pp. 201–229.