Journal for Nature Conservation 81 (2024) 126685

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc

A cost-benefit analysis of ecosystem services from restoring degraded soils to forest ecosystems in the Sahel

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ARTICLE INFO

Keywords:
Sustainable Land Management
Forest Restoration
Ecosystem Services
Cost-benefit analysis
Net Present Value

ABSTRACT

Techniques of degraded ecosystems restoration in the Sahel have largely contributed to slowing down desertification process. However, they are often very costly, requiring important manpower and financial resources. The economic benefits of such cases of land restoration are under-documented, especially in scientific literature. The aim of this study is to estimate the ecosystem benefits (market and non-market, direct and indirect) associated with changes in biodiversity induced by forest and landscape restoration (FLR) interventions in the Sahel, and to compare them with the costs of these interventions. Data has been compiled using individual and group surveys, floristic inventory, and existing literature. Ecosystem services framework has been used to structure the analysis. Financial and economic cost-benefit analysis have been compiled, based on the historical case of the managed Gourga forest (Ouahigouya, North Burkina Faso), to estimate whether FLR brings benefits greater than it costs. The results show that restoration of the site is profitable over the first ten years thanks to farming activities, becoming unprofitable in years 11–45 after farming is completely stopped. This study opens up new prospects for improved design of FLR in the Sahel.

1. Introduction

Sahelian West Africa is undergoing an environmental crisis that is affecting savannah ecosystems in particular, leading to desertification, drought and deforestation (Gangneron et al., 2022). Since the early 1970s, an unprecedented drought cycle has set in the Sahel (Ozer et al., 2010; Benjaminsen & Hiernaux, 2019). It is in this context that the West African States introduced a number of subregional policy instruments aiming to curb the environmental crisis caused by these droughts. These include the establishment of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), which currently brings together the Sahelian countries and other forest countries of West Africa. At the level of agricultural producers, a new approach of forest resources management and agricultural practices has become necessary in light of food security issues and lack of private investment in land restoration.

The goal of forest and landscape restoration (FLR) is to restore ecological functions and ecosystem services in degraded areas (Schweizer et al., 2021). The restoration of degraded ecosystems is essential in conservation projects and the quest for sustainable human development (Aronson & Alexander, 2013; Abhilash, 2021). It is an activity that is widely carried out in several countries and involves all types of ecosystems, from wetlands, forests and grasslands to coral reefs and mangroves (Millennium Ecosystem Assessment, 2005). In Europe, recent study shows that pollution via pesticides remains one of the main factors contributing to land degradation (Prăvălie et al., 2024). In the contest of Burkina Faso, human activities are the most important threat to the

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https://doi.org/10.1016/j.jnc.2024.126685
Received 14 January 2024; Received in revised form 29 June 2024; Accepted 15 July 2024
Available online 18 July 2024

conservation of plants, overshadowing climatic factors (Bayen et al., 2024).

Forest ecosystems conservation and restoration is considered one of the best solutions to mitigate climate change (Anderegg et al., 2022), also bringing benefits in return (Clewell & Aronson, 2006). Forest landscape restoration can be used as a general framework for rehabilitation of degraded dryland ecosystems (Yirdaw et al., 2017). Approaches tried and tested by people most and regularly affected by droughts tend to allow for greater resilience to climate change (Popovici et al., 2021), and tend to carry greater influence with their peers. Yacouba Sawadogo of Gourga transformed 27 ha of bare soil into fairly dense vegetation over a 45-year period by testing out several techniques. The techniques developed and disseminated on the basis of this experience led to increase significantly agricultural production and re-green lands and landscapes in several areas of the Sahel, including Mali, Burkina Faso and Niger (Gabou & Maisharou, 2015; Delvaux & Riesgo, 2020). Despite the great efforts devoted to reforestation, the most effective method is the natural approach (Carey, 2020), as used in this study by Yacouba Sawadogo.

However, such techniques are often very costly, requiring a lot of manpower and financial resources (Schuler et al., 2016). Actual benefits of land restoration are under-documented (Keudem & Savadogo, 2023), leading to gross misrepresentation of actual returns on restoration and a misapprehension of actual incentives and barriers to restoration. This is because, very often, non market benefits are harder to assess than financial costs well accounted for (Snell, 2011). As stated by Yirdaw et al. (2017), there is a real need for cost-benefit analyses of ecosystem rehabilitation in dry lands. Yet, there is a dearth of published studies investigating the financial set up of investments into land rehabilitation, especially in academic literature. The World Overview of Conservation Approaches and Technologies (WOCAT, https://www.wocat.net) documents case study data when available. Nkonya et al (2016) investigates the cost of land degradation rather than rehabilitation drivers. Recently, the Economics of Land degradation (ELD) Initiative led to the compilation of case studies in Senegal, Niger, Mali and Ghana as well as another four countries in East Africa, as an effort to improve economic perspectives over restoration efforts (https://www.eld-initiative.org). Most published studies and reports do not have a long-term perspective over land restoration efforts, and lack perspective in individual incentives to restore land. The lack of micro-economic data – because of lack of monitoring or because such data is not readily accessible to research nor public agencies – hinders progress on better understanding local drivers of land rehabilitation and how to better design land rehabilitation projects. This paper aims to contribute to filling this gap in the literature by putting together a cost-benefit analysis of FLR in Burkina Faso, to assess financial and economic viability of FLR conducted over a 45-year period.

2. Material and methods

2.1. Study site: the Gourga managed forest (27 ha)

The study site is the Gourga managed forest. Covering an area of 27 ha, it is located in the township of Ouahigouya, in northern Burkina Faso (Fig. 1). The main soil types are lithosols on cuirass, ferruginous soils and soils with little gravel erosion. From a lithological point of view, Ouahigouya is part of the crystalline zone.

Ouahigouya belongs to the drylands biome as described by Metzger

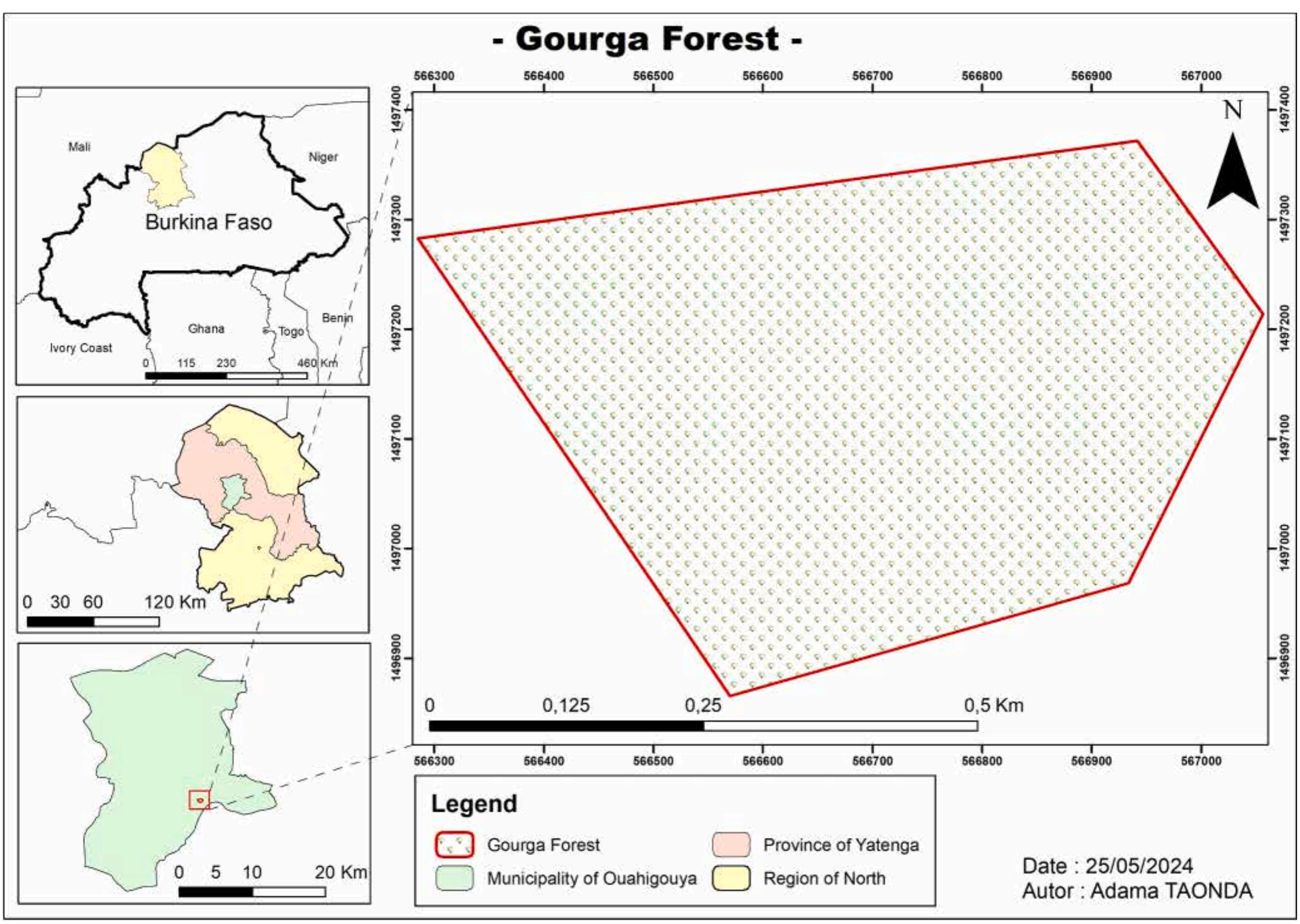

Fig. 1. Location of the study site.

et al. (2013). The climate is sudano-sahelian, with alternating wet and dry seasons. Average rainfall is between 500 and 600 mm, concentrated between June and September. The main vegetation types are steppe, tiger bush, shrub savannah and tree savannah. In terms of phytogeography, Ouahigouya is located in the sub-Sahelian zone. The main woody species around Ouahigouya are *Lannea microcarpa* Engl. & K.Krause, *Combretum micranthum* G.Don, *Combretum glutinosum* Guill. & Perr. and *Guiera senegalensis* Lam. Large mammals have disappeared from the natural ecosystems due to the absence of refuge areas (dense formations), but also because of strong human pressure and unfavourable bioclimatic conditions. Nowadays, fauna is composed of small mammals (rats, hares), which can be spotted in places, and a fairly diverse avifauna.

Ouahigouya has a population of around 124,000. The inter-censal growth rate of the population was 2.91 per cent between 2006 and 2019 in the region of Ouahigouya (RGPH, 2022). Agriculture and livestock farming are the main activities. Farming is mainly for food, with little mechanization, and highly dependent on natural conditions. Zaï (fertilized pits all over a field) and stone-rows are frequently used to enhance water availability for seeds and crops. The main crops are sorghum, millet, cowpeas, groundnuts, maize, sesame and Bambara groundnut.

2.2. Restoration work: 1973–1982 (years 1–10) and 1983–2018 (years 11–45)

Soil restoration has begun in 1973, out of the initiative of Yacouba Sawadogo, a local innovative famer, on his own land (in the restored site, a small control area remains.; Fig. 2) His rationale has been to focus on techniques supporting vegetation growth, in order to regreen the site. Local woody species have been planted as an effort to rehabilitate the land (Fig. 3). The time was divided into two. The period 1–10 years correspond to the period where the restored site was used to product crop. In contrast, during the period 11–45 years, crop production was abandoned so that plants can grow and the vegetation was restored. The site has been restored using zaïs, i.e. digging small pockets of soil to collect rainwater for the benefit of seeds (Roose et al., 1999). Zaïs have been combined with stone-rows, organic fertilisers, plantations and assisted natural regeneration during the first ten years, fostering agricultural productivity as a side effect of forest rehabilitation.

From the eleventh year, crops have been gradually abandoned and replaced by a fallow that evolved over time into a shrubby plant formation. The post-cultivation period is characterised by complete protection of the site: logging, fires and animal grazing are strictly

Fig. 2. Control plot in the middle of Gourga forest showing that the restored site where a degraded land with encrusted soil.

Fig. 3. Wooded savannah resulting from Gourga forest restoration activities.

prohibited. This is because forest rehabilitation had always been envisioned to be followed by complete protection to avoid past overexploitation that had led to the bare land in the first place.

All restoration work has been carried out without cash for work, i.e. without any financial, technical or material support from the state. The workforce mobilised for this purpose was family-based, often supplemented by external labour paid on an ad hoc basis. This is important in terms of having an example of restoration work that can be conducted out of private initiative, rather than large-scale efforts induced by government or international donors.

3.1. 2.3 Cost-benefit analyses (CBA)

Hanley and Barbier (2009) define economic CBA as a technique for determining whether the benefits of a given action outweigh the costs to society as a whole. According to the same authors, "action" means a deliberate decision to commit resources to carry out a project. CBA requires all changes induced by the "action" to be valued in economic terms, leading to rely on economic valuation techniques (Ackerman & Heinzerling, 2001). Non-demand valuation methods such as the replacement cost method and benefit transfer techniques have been used to estimate non-market benefits. We chose a domestic price system and the local currency (FCFA) to compile the analyses.

Firstly, a financial cost-benefit has been compiled, based on actual monetary flows (or monetary flows that would be incurred if production was not self-consumed). Such financial CBA includes subsidies, taxes, and does not take account of possible price distortion (eg, due to minimum wage legislation, etc). Because of the shift in restoration approaches, one financial CBA has been conducted for the years 1–10 and another for years 11–45. This form of CBA allows to capture actual incentives faced by local land users for FLR.

Secondly, financial analysis has been adapted to obtain an economic analysis – ie an analysis that excludes transfer payments such as taxes and subsidies and corrects for price distortions. This is to obtain an analysis that reflects actual values to society as a whole, independent of wealth redistribution mechanisms within such society. Again, economic CBA have been compiled for years 1–10 separate from years 11–45.

Financial and economic analyses have been supplemented by sensitivity analysis, to check results reliability over changes in parameters. Because data is scarce and difficult to cross-check with unavailable alternative sources, sensitivity analysis allows to assess whether results hold over various configurations. If they do not, then the incentive structure around FLR changes, which could lead to the exact opposite outcome.

Discount rates are set at 1 %, 5 % and 10 %, to capture "standard" preference for the present (1 % indicating low preference for the present, and 10 % a higher one). Discount rates have been increased up to 1000 % in sensitivity analysis to check whether results would hold for populations with almost infinite preference for the present – typically land users in the Sahel focused on their survival and food security.

Three situations have been considered for each CBA (years 1–10 and years 11–45): initial situation, path 1 and path 2. For years 1–10, the initial situation corresponds to what prevailed just before the restoration work in 1973. It is characterised by degraded bare soil, almost without vegetation and with very low yields. From this initial situation, two mutually exclusive paths can be taken. Path 1 corresponds to a reference situation (counterfactual) derived from foreseeable evolution over time of the initial situation, without any restoration action. Crops are still seeding without the use of zaï or stone-rows. Path 1 mostly resembles the initial situation, with a few changes. Path 2 corresponds to the situation with adoption of FLR/SLM actions (zais, stone walls, organic fertilisers, assisted natural regeneration and planting of local woody species). Yields are high, but this situation requires more resources in terms of equipment and labour compared to the initial situation or Path 1.

After ten years, crop cultivation is abandoned. For years 1–10, the initial situation corresponds to Path 2 described above at year 10, with land left fallow. From this initial situation, two paths can be taken. Path 3 corresponds to a reference situation where cultivation is maintained on the restored site, as is currently practiced around the Gourga forest. Path 4 is the one currently observed on the site: thanks to strict protection, fallow land has evolved into dense and highly diversified plant formations that have sequestered significant quantity of CO_2. NTFPs, honey and medicinal plants (pharmacopoeia) are collected. Expenses are limited to labour required to collect the products and maintain stone-rows.

The net flows with SLM (A) and without SLM (B) were used to calculate the additional net flow as the difference between the former and the latter (A-B). The conversion factor applied to correct the exchange rate and therefore the prices of imported products is 0.94 for economic analysis (Couharde et al., 2012). The sensitivity analysis is conducted under the assumption of a successive drop of −10 % in the value of each variable, to identify the one most likely to affect the conclusions derived from the CBA viability indicator (net present value).

3.2. 2.4 Data collection methods

Several approaches have been used to collect data for estimation of costs and benefits of ecosystem services associated with Gourga forest restoration. 30 individual surveys have been conducted in the village of Gourga, of people involved in restoration activities. In the same village, such individual surveys have been supplemented by a focus group with Yacouba Sawadogo and his relatives. The questionnaire has been designed to collect data on the initial state of the site, types of restoration techniques used, work duration required by each FLR technique, scale of each restoration structure, costs of equipment and inputs purchased, uses of local biodiversity, types of forest products harvested on the site, market value of species traded and agricultural yields before and after restoration. Qualitative data on biodiversity and the impact of the benefits perceived after restoration on households' quality of life have also been collected. Collected data therefore capture investment costs into FLR, as well as costs and benefits of activities conducted on the site before and after restoration.

Because of the nature of FLR, cost and benefit data have been structured along the four categories of ecosystem services: provisioning, regulating, supporting and cultural (Millennium Ecosystem Assessment, 2005). Many provisioning services identified in the survey and focus group have some market value that can be used to estimate benefits, even if they remain non-marketed (e.g., subsistence farming). The replacement cost method has been used to estimate their market value. Economic values of regulating services (hydrological flow, water purification, waste treatment, pollination, regulation of natural phenomena) and cultural services (spiritual and inspirational, recreational, aesthetic, educational) have been assessed on the basis of values taken from De Groot et al (2012) using the benefit transfer method. The conversion rate was 617 FCFA (XOF) for 1 USD (2024 rate).

Revenues have been calculated on the basis of market prices or prices proposed in the literature by multiplying unit prices by the quantities obtained. The surveys also provided information on working hours and the costs associated with catering activities. Operating costs include labour for the construction of works and agricultural activities, the purchase of inputs and tools. Investments include works carried out (zaï, stone-rows) and multi-year tools such as wheelbarrows, crowbars, etc. The price sources associated with each variable and the values used are shown in Appendices A and B. The reference year for prices is 2018.

3. Results

3.1. Ecosystem services and CBA results for the cropping period

The results show that the costs of restoration actions consist mainly of labour for agricultural activities and soil development (zaï, stone-rows, organic amendment) (Appendix A). Over the period starting from year 1 to year 10, during which crops are grown, the ecosystem services identified and monetised consist of provisioning services (crop products) and regulating services (CO_2 sequestration). Cultural services (spiritual, recreational, aesthetic, education, support services, etc.) have been identified but not monetised (Appendix B).

Tables 1 and 2 present a summary of the analyses and the main variables affecting the analysis of sensitivity over the 1–10 year period. Financially and economically, SLM is cost-effective compared with the situation without SLM. The results show a positive net present value (NPV) of 43 million FCFA in the financial analysis and 95 million FCFA in the economic analysis for a discount rate of 10 %. SLM is viable and highly profitable compared to the situation without SLM (Table 1).

Assuming a 30 % drop in crop yields − which is common in years of poor rainfall − SLM is still profitable compared to the situation without SLM. However, there is a 48 % drop in profits (NPV = 49.1 million for a discount rate of 10 %). From an economic point of view, crop-related gains here represent the bulk of the ecosystem benefits of transforming degraded land into agricultural land. SLM with zaï alone (without stone cordons) increases the NPV by 32 %. The other operations − particularly the stone-rows − weigh less heavily on the investment required.

Assuming a 30 % increase in the price of the organic amendment (zaï is practised with a substantial organic amendment), the results show a reduction in NPV of only 4 %. This can be explained by the fact that most of the investment required for zaï and stone-rows is concentrated at the beginning of restoration activities.

By successively lowering the value of the variables by −10 %, the sensitivity analysis shows that sorghum and cowpea cultivation as well as planting operations along stony cordons are the main variables that reduce the NPV by −2 to −12 % (Table 2).

Table 1
Summary of variables from financial, economic and sensitivity analyses over the 01–10 year period (NPV in million FCFA).

Discount rates	1 %	5 %	10 %
Financial analysis	66.5	54.1	43.0
Economic analysis	146.5	119.4	95.0
Sensitivity analysis: 30 % drop in crop yields (sorghum and cowpea)	75.9	61.8	49.1
Variation (%)	−48 %	−48 %	−48 %
Sensitivity analysis: SLM with zaï alone (without stone-rows)	193.7	157.9	125.6
Variation (%)	32 %	32 %	32 %
Sensitivity analysis: increase in the price of organic amendment by 30 %	140.8	114.7	91.2
Variation (%)	−4%	−4%	−4%

Table 2
Main variables affecting the sensitivity analysis with the systematic method for the 01–10 year period.

Price variation (−10 %)	NPV before variation (million FCFA)	NPV after variation (million FCFA)	NPV variation (%)
Incoming flows			
Sorghum (in zaï)	95.0	83.3	−12 %
Cowpea (in zaï)	95.0	91.3	−4%
Outgoing flows			
Stone-rows: planting (labour)	95.0	93.2	−2%

Table 4
Main variables affecting sensitivity analysis with the systematic method for the 11–45-year period.

Price variation (−10 %)	NPV before variation (million FCFA)	NPV after variation (million FCFA)	NPV variation (%)
Incoming flows			
Sorghum (in zaï)	−122.9	−112.9	−8%
Cowpea (in zaï)	−122.9	−119.5	−3%
Outgoing flows			
Stone-rows: planting (labour)	−122.9	−125.3	2 %

3.2. *Ecosystem services and CBA results after the cropping period*

The ecosystem services identified and monetised comprise provisioning services (edible leaves and fruit, honey, fodder), regulating services (CO_2 sequestration, regulation of hydraulic flows, water and air purification) and cultural services (spiritual, recreational, aesthetic, educational, etc.). Soil restoration has indeed enabled soil formation and the resetting of the nutrient cycle, as demonstrated by the improved fertility of restored soil (Cissé et al., 2022; Maïga-Yaleu et al., 2022). These services support other services and have not been monetised (Appendix C) because their benefits are found in provisionning services. The costs identified consist mainly of labour for monitoring the site, planting woody species along the stone-rows and purchasing tools (Appendix D).

The results of the CBA show that the producer worked at a loss to restore the site by opting for complete protection of the site without agricultural development. The results of the economic, financial and sensitivity analyses are presented in Table 3. The practice of SLM over this period is not profitable for the farmer compared with the "no SLM" situation (i.e. agricultural production and no full protection of the site after year 10). In other words, the farmer is deprived himself of the benefits of the SLM measure that he would have reaped if he had continued to grow crops on the site. This financial windfall amounts to 118.9 million FCFA over 35 years. The variables that affected the sensitivity analysis in the first period were also affected in the second period (Table 4).

4. Discussion

During the farming phase (years 1–10), equipment used to restore the site is limited and fairly low tech (*dabas*, pickaxes). Digging up the zaïs and installing the stone-rows are labour-intensive activities (Roose et al., 1999; Clavel et al., 2016). This explains why labour constitutes the bulk of the cost of restoration. The development of mechanised zaï by cross-subsoiling has been implemented in Burkina Faso (Sawadogo et al., 2011) but is still used very little. This mechanisation, for example, can cut labour time per hectare by a factor of seven (from 300 h/ha to 40 h/ha) (Clavel et al., 2016). Agricultural machinery is available for all cultivation operations, but Burkina Faso's agriculture is still characterised by low levels of mechanisation. The economic model of farms (self-consumption farming, small surface area) does not allow for the acquisition of modern tools. Although costly, the use of organic fertilisers is encouraged for ecologically sustainable restoration. The positive net present benefit obtained from CBA suggests that farmers could have the right incentives to restore land in the Gourga region, and obtain higher benefits. Why they do not follow their neighbour's example suggests there may be other reasons for not doing so themselves: lack of access to labour, lack of access to sufficient funding to pay for sufficient labour, lack of access to organic fertiliser (or lack of means of access), etc.

During the plant cover regeneration phase, official security has been a crucial factor in the success of the operation. That is why decision makers of Burkina Faso support strongly forest protection through the Water and Forestry Corps, whose daily work is to guard the formations against intrusions of all kinds. However, the success of the Gourga forest is due more to the will of its promoter to ensure its protection assiduously and relentlessly.

Non-timber forest products are tangible services derived from the reconstituted forest. In monetary terms, carbon sequestration and regulation services (hydrological flows, water purification, pollination), although poorly monetised, are very important benefits that have an impact on the environment (IPCC, 2022) and plant production well beyond the reconstituted forest. Ackerman & Heinzerling (2001) referred to the difficulty of evaluating, for example, a healthy environment in terms of the services provided by the forest. The microclimate generated by the forest could not be fully quantified in monetary terms, given the inestimable benefits it has for people's health, the local climate and so on.

As Yirdaw et al. (2017) state, the prospect of restoring degraded drylands is technically promising and this study further demonstrates that it is economically feasible. During the agricultural exploitation phase of the site, the CBA clearly indicates the economic and financial profitability of such an activity. Other studies conducted in the Sahel support the adoption of zai, stone-rows and ANR as techniques suitable for farming degraded land (Roose et al., 1999, ELD Initiative 2019–2020 case studies).

However, over the period of forest cover regeneration, the CBA shows that this activity is not financially nor economically profitable for the producer. Incentives faced by land users work against strict protection of the forest. This suggests that the landowner was willing to take a financial loss in order to restore forest effectively. This attitude leads us to wonder about the real philosophy that leads man to protect nature (Ratcliffe, 1976): is it because of the spin-offs or because of an intrinsic love of nature? This attitude is likely to not be shared by his neighbours: incentives to restore are stronger is benefits are greater than before, which is not the case here.

Table 3
Summary of variables from the financial, economic and sensitivity analyses over the 11–45 year period (NPV in million FCFA).

Discount rate	1 %	5 %	10 %
Financial analysis	−190.9	**−153.0**	−118.9
Economic analysis	−197.2	**−158.1**	−122.9
Internal rate of return	1997		
Sensitivity analysis: 30 % drop in crop yields (sorghum and cowpea)	−132.1	**−106.1**	−82.7
Variation (%)	-33 %	-33 %	-33 %
Sensitivity analysis: SLM with zaï alone (without stone-rows)	−197.2	**−158.1**	−122.9
Variation (%)	0 %	0 %	0 %
Sensitivity analysis: 30 % increase in the price of organic fertiliser	−192.0	−153.8	−119.5
Variation (%)	−3%	−3%	−3%
Sensitivity analysis: SLM without planting along stone-rows	**−235.4**	−188.6	−146.5
Variation (%)	19 %	19 %	19 %

The financial windfall lost due to the absence of a harvest in parallel with the adoption of SLM over the period 11–45 years was estimated at 118.9 million CFA francs, which is very high for an average producer in Burkina Faso. However, this potential harvest loss is tempered by the timber production (usable as energy or for other services) during this period, which constitutes potentially high economic capital for the promoter. However, the fact that this study assesses the carbon sequestration in this wood means that the monetary value of this wood cannot be taken into account, as this would result in a double assessment of the same thing.

Other cost-benefit analyses of the restoration of other sites conclude that there are net benefits when fruit plants are used (Suo & Cao, 2021). In the present study, most of the species were used much more for their adaptation to the semi-arid climate than for their uses (fruit, medicines, etc.). In addition, when forest management involves assiduous exploitation of resources, the benefits are clear for the population (Anguti et al., 2022). Apart from the exploitation of surplus herbaceous production such as fodder and the exploitation of honey and some fruit plants, this study has shown that the trees resulting from the restoration of the site are not intensively exploited. All this contributes to a negative NPV to the detriment of the promoter of the Gourga forest. As said Verdone (2015), decision can be taken from the value of the NPV but other factors influence the ultimate decision to be taken for the restoration of degraded ecosystem.

A 30 % increase in the price of the organic amendment would have a minimal impact on the NPV, reducing it by only 4 %. This suggests that while the organic amendment may be essential from an agronomic perspective, it does not significantly affect the economic success of the development. Additionally, the integration of agriculture and livestock farming, as well as the reuse of harvest residues in composting, provide ample manure for site restoration operations. Small-scale producers with limited incomes may not be able to make such an investment without state support.

According to Wild and Walters (2022), the main financial challenges in implementing FLR is the short duration and availability of funding, the high cost of initial activities, and the low short-term return on investment. The restoration of the site is currently under threat due to the potential development of housing, which raises concerns about land pressure and the success of this globally recognised initiative. Despite Yacouba Sawadogo's renowned work, the desire for financial gain is driving the appropriation of land for housing, given the urbanisation of the area. This raises the question of whether homes will need to be demolished in order to restore the forest ecosystems. An analysis of urban development reveals that the forest will be incorporated into a residential area in the short term, and will likely transform into an urban park in the medium to long term. The municipality of Ouahigouya has a significant responsibility to secure and develop the site.

5. Conclusion

The study consisted of documenting the costs of the intervention and measuring parameters that would allow a monetary value to be placed on the direct and indirect benefits of restored forest on degraded land in the Sahel over a 45-year period. The study found that investment in FLR can deliver net benefits, but only if it is designed to do so. Private initiatives should be managed to ensure net benefits, and lessons learned should be disseminated to encourage adoption and improvement by peers. Degraded soils can be regenerated, but only with a sustained human commitment over a period of decades. These results can enrich the discourse on financing land and landscape restoration activities, and open up new perspectives on the economic and environmental opportunities for restoring the ecological resilience of these ecosystems and conserving biodiversity in the Sahel. Future research could explore the real motivations behind people's private initiatives to invest in ecosystem restoration, beyond the immediate return on investment.

CRediT authorship contribution statement

Sibiry Albert Kaboré: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Emmanuelle Quillérou:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Stéphanie Maiga-Yaleu:** Writing – review & editing, Visualization, Project administration, Conceptualization. **Maguette Kairé:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Ibrahim Bouzou Moussa:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Oumarou Malam Issa:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Data curation, Conceptualization. **Damien Hauswirth:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hassan Bismarck Nacro:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank the CBD (Convention on Biological Diversity) and FERI (Forest ecosystem restoration initiative) for funding this work. They would also like to thank late Yacouba Sawadogo for accepting his forest to be investigated. Many thanks to the European Institute for Marine Studies (IUEM) for hosting the first author's research visit, which enabled the analysis of the data. The authors thank the anonymous reviewers for their valuable comments.

Appendix A. . Estimated costs and net flows of restoration actions for the cultivation period (1–10-year) (Site area: 27 ha)

Expenditure items	Outgoing flows (FCFA)
Working capital requirement	**0**
Operating expenses (agriculture)	
Labour works	
Site monitoring	1,964,030
Labour for agricultural activities (in the broadest sense)	
Agricultural labour (sowing, weeding, harvesting, etc.)	136,391

(*continued on next page*)

(*continued*)

Expenditure items	Outgoing flows (FCFA)
Farm labour for NTFP harvesting	6,820
RNA (labour)	2,700,000
Farming inputs	
Organic fertlisers	2,025,000
Tools (annual) and maintenance	
Gloves and boots	5,000
Cart maintenance costs	20,000
Donkey servicing cost	120,000
Total operating expenses	**6,977,241**
Investment	
Works (establishment = workforce)	
Zaï (cowpea and sorghum, replanted annually)	2,362,500
stone-rows (labour)	1,000,000
(Multiannual) tools and materials for conducting the activities	[2]
Plantation (plant)	300,000
Pickaxe	15,000
Cart	300,000
Donkey	80,000
Shovel	30,000
Mining rod	50,000
Wheelbarrow	125,000
Daba	30,000
Zaï-sou	60,000
Total investment	4,352,500
Total outflows	11,329,741
Net flows with SLM (1–10 years)	14,373,563
Net flows without SLM (baseline)	234,631
Net flows without SLM (baseline)	234,631

Daba and *zaï-sou*: small ploughing equipment.

Appendix B. . Estimated benefits from ecosystem services for the cropping period (1-10th year) (Site area: 27 ha)

Ecosystem services	Incoming flow (FCFA)
Provisionning services	
Sorghum	19,089,000
Cowpea	6,595,000
Non-timber forest products (NTFP)	12,500
Regulation services	
CO_2 sequestration in biomas/year	7,515
Cultural services	
Spiritual, recreational, aesthetic, educational (non-monetised-NA)	Rm
Support services (non-monetarised-NA)	Rm
Soil formation (non-monetised – NA)	Rm
Nutrient cycle (not monetised – NA)	Rm
Total incoming flows	**25,704,035**

rm: as a reminder.

Appendix C. . Estimated ecosystem service benefits for the post-cultivation period (11th to 45th year) (Site area: 27 ha)

	Starting situation	Reference situation	Situation with change (adoption of SLM)
Provisionning services			
Sorghum (in zaï)	19,089,000	19,089,000	0
Cowpea (in zaï)	6,520,200	6,520,200	0
NTFP: potential products of plants throughout the forest (edible leaves and fruit).	12,500	125,000	20,448,450
Honey	0	0	40,000
Mown fodder	0	0	87,500
Wood energy	0	0	0
Pharmacopoeia	0	0	50,000
Genetic material	0	0	0
Regulation services			
CO_2 sequestration from biomass/year(excluding mown fodder)	7,515	12,317	123,166
Regulation (hydrological flow,water purification, pollination etc.)	0	0	849,609
Cultural services			
Spiritual, recreational, aesthetic, educational	0	0	116,613
Support services (non-monetized – NA)	0	0	0
Soil formation (non-monetized – NA)	0	0	0
Nutrient cycling (non-monetized – NA)	0	0	0

Appendix D. . Estimated costs and net flows (FCFA) of restoration actions for the post-cultivation period (11–45-year period.) (Site area: 27 ha)

Year	11	12	13	43	44	45
Working capital requirement	2,579,241	0	0	0	0	2,518,735
Labour works						
Labour for annual maintenance of stone-rows	0	13,257	13,257	13,257	13,257	13,257
Site monitoring	707,051	707,051	707,051	707,051	707,051	707,051
Labour agricultural activity(Sowing, weeding, harvesting, etc.)	429,632	0	0	0	0	0
Farm labour for NTFP harvesting	2,455	62,849	62,849	62,849	62,849	62,849
Farm labour for forage harvesting	0	14,730	14,730	14,730	14,730	14,730
Farm labour for honey harvesting	0	2,946	2,946	2,946	2,946	2,946
RNA (labour)	972,000	0	0	0	0	0
Organic fertilisers	2,025,000	0	0	0	0	0
Tools (annual) and maintenance						
Gloves and boots	4,700	14,100	14,100	14,100	14,100	14,100
Cart maintenance costs	20,000	10,000	10,000	10,000	10,000	10,000
Donkey servicing cost	120,000	60,000	60,000	60,000	60,000	60,000
Total operating expenses	4,108,985	884,933	884,933	884,933	884,933	884,933
Investment						
Zaï (cowpea and sorghum, grown annually)	510,300	0	0	0	0	0
Stone-rows: labour	0	0	0	0	0	0
Stone-rows: planting (labour)	0	0	0	0	0	0
Stone-rows: planting (plants associated with stone-rows)	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000
ickaxe	15,000	0	7 500	0	7,500	0
Cart	265,000	0	0	0	0	0
Donkey	80,000	0	0	0	0	80,000
Shovel	18,000	0	0	0	1,800	0
Mining rod	47,000	0	0	47 000	0	0
Wheelbarrow	110,450	0	0	0	44,180	0
Daba	30,000	0	0	10 000	6,000	0
Zaï-sou	60,000	0	0	60 000	0	0
Total investment	4,147,830	3,000,000	3,007,500	0	13,000	0
Total incoming flows	25,703,304	703,576	1,387,867	20,407,286	21,008,343	21,609,400
Total outflows	5,677,574	3,884,933	3,892,433	884,933	897,933	3,464,175
Net flows with SLM (1–10)	19,951,941	−3,173,112	−2,488,806	19,628,289	20,216,347	18,251,163
Net flows without SLM (reference situation)	18,661,284	22,633,994	22,602,027	22,693,262	22,738,262	22,693,262
Additional net flows	1,290,657	−25,807,106	−25,090,833	−3,064,972	−2,521,915	−4,442,099

Daba and *zaï-sou*: small ploughing equipment.

References

Abhilash, P. C. (2021). Restoring the unrestored: Strategies for restoring global land during the UN decade on ecosystem restoration (UN-DER). *Land, 10*(2). https://doi.org/10.3390/land10020201. Article 201.

Ackerman, F., & Heinzerling, L. (2001). Pricing the priceless: Cost-benefit analysis of environmental protection. *U. Pa. L. Rev., 150*. Article 1553 https://heinonline.org/HOL/LandingPage?handle=hein.journals/pnlr150&div=42&id=&page=.

Anderegg, W. R., Wu, C., Acil, N., Carvalhais, N., Pugh, T. A., Sadler, J. P., & Seidl, R. (2022). A climate risk analysis of Earth's forests in the 21st century. *Science, 377* (6610), 1099–1103. https://doi.org/10.1126/science.abp9723

Anguti, S., Mukadasi, B., & Andama, E. (2022). Cost-benefit analysis of collaborative forest management: a case study of Tororo Central Forest Reserve, Eastern Uganda. *East African Journal of Forestry and Agroforestry, 5*(1), 76–95. https://doi.org/10.37284/eajfa.5.1.745

Aronson, J., & Alexander, S. (2013). Ecosystem restoration is now a global priority: Time to roll up our sleeves. *Restor. Ecol., 21*(3), 293–296. https://doi.org/10.1111/rec.12011

Bayen, P., Bognounou, F., Ganamé, M., Balma, E. N., Lykke, A. M., & Thiombiano, A. (2024). Enhancing tree species conservation in Burkina Faso through indigenous knowledge. *J. Nat. Conserv., 126626*. https://doi.org/10.1016/j.jnc.2024.126626

Benjaminsen, T. A., & Hiernaux, P. (2019). From desiccation to global climate change: A history of the desertification narrative in the West African Sahel, 1900–2018. *Global Environment, 12*(1), 206–236. https://doi.org/10.3197/ge.2019.120109

Carey, J. (2020). The best strategy for using trees to improve climate and ecosystems? Go natural. *Proc. Natl. Acad. Sci., 117*(9), 4434–4438. https://doi.org/10.1073/pnas.2000425117

Cissé, A. C., Maïga-Yaleu, S. B., Kaboré, S. A., Kairé, M. B., Hauswirth, D., Moussa, I. B., & Nacro, H. B. (2022). Long-term effect of forest and landscape restoration practices on soil organic carbon stock in semi-arid Burkina Faso. *IJBCS, 16*, 329–344. https://doi.org/10.4314/ijbcs.v16i1.28

Clavel, D., Barro, A., Belay, T., Lahmar, R., & Maraux, F. (2016). Burkina Faso: L'évolution de la technique du zaï. *Agridape, 32*(1), 18–20. https://agritrop.cirad.fr/581994/1/AGRIDAPE%2032.%201%20mars%202016.pdf.

Clewell, A. F., & Aronson, J. (2006). Motivations for the restoration of ecosystems. *Conserv. Biol., 20*(2), 420–428. https://doi.org/10.1111/j.1523-1739.2006.00340.x

Couharde, C., Coulibaly, I., & Damette, O. (2012). La dynamique d'ajustement des taux de change réels dans la zone franc CFA. *Revue économique, 63*(3), 545–555. https://doi.org/10.3917/reco.633.0545. URL

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Luis, C., Rodriguez, L. C., Brink, P., & van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv., 1*(1), 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

Delvaux, G., & Riesgo, L. (2020). Sustainable agricultural practices and their adoption in sub-Saharan Africa: A selected review, EUR 30283 EN. *Publications Office of the European Union, Luxembourg.*. https://doi.org/10.2760/360761, JRC121035

Gabou, M. H., & Maisharou, A. (2015). Management practices/techniques commonly used in Niger Republic, In R. Lal, B. R. Singh, D. L. Mwaseba, D. Kraybill, D. O. Hansen & L. O. Eik (Eds.), *West Africa. Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa*, (pp. 305-314)). Cham: Springer International Publishing.

Gangneron, F., Pierre, C., Robert, E., Kergoat, L., Grippa, M., Guichard, F., Hiernaux, P., & Leauthaud, C. (2022). Persistence and success of the Sahel desertification narrative. *Reg Environ Change, 22*(4), 1–11. https://doi.org/10.1007/s10113-022-01969-1

Hanley, N., & Barbier, E. B. (2009). *Pricing nature: Cost-benefit analysis and environmental policy*. Edward Elgar Publishing.

Intergovernmental Panel on Climate Change (IPCC). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press;. doi:10.1017/9781009325844.

Keudem, G. G. L., & Savadogo, K. (2023). Land tenure security and agricultural production in the rural areas of Burkina Faso.

Maïga-Yaleu, S. B., Cissé, A. C., Kaboré, S. A., & Nacro, H. B. (2022). Impact des propriétés physico-chimiques du sol sur la perte de carbone par émission de CO_2 sous combinaison de pratiques de restauration des forêts et des paysages. *Journal de la Société Ouest-Africaine de Chimie, 51*, 78–86.

Metzger, M. J., Bunce, R. G., Jongman, R. H., Sayre, R., Trabucco, A., & Zomer, R. (2013). A high resolution bioclimate map of the world: A unifying framework for global biodiversity research and monitoring. *Glob. Ecol. Biogeogr., 22*(5), 630–638. https://doi.org/10.1111/geb.12022

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington DC: Island Press.

Nkonya, E., Mirzabaev, A., & Von Braun, J. (2016). *Economics of land degradation and improvement–a global assessment for sustainable development* (p. (p. 686).). Springer Nature.

Ozer, P., Hountondji, Y., Niang, A. J., Karimoune, S., Laminou Manzo, O., & Salmon, M. (2010). Désertification au Sahel: Historique et perspectives. *Bulletin de la Société Géographique de Liège, 54*, 69–84. https://hdl.handle.net/2268/10347.

Popovici, R., Moraes, A. G. de L., Ma, Z., Zanotti, L., Cherkauer, K. A., Erwin, A. E. , Mazer, K. E., Bocardo Delgado, E. F., Pinto Cáceres, J. P. , Ranjan, P., & Prokopy, L. S. (2021). How do Indigenous and local knowledge systems respond to climate change? *Ecology and Society 26(3):*27. doi: 10.5751/ES-12481-260327.

Prăvălie, R., Borrelli, P., Panagos, P. Ballabio C., Lugato, E., Chappell, A., Miguez-Macho, G., Maggi, F., Peng, J., Niculiță, M., Roșca, B., Patriche, C., Dumitrașcu, M., Bandoc, G., Andrei Nita, I. & Birsan M.-V.. (2024). A unifying modelling of multiple land degradation pathways in Europe. *Nat Commun* 15, 3862 (2024). doi: 10.1038/s41467-024-48252-x.

Ratcliffe, D. A. (1976). Thoughts towards a philosophy of nature conservation. *Biol. Conserv., 9*(1), 45–53. https://doi.org/10.1016/0006-3207(76)90073-2

Roose, E., Kaboré, V., & Guenat, C. (1999). Zaï practice: A West African traditional rehabilitation system for semiarid degraded lands, a case study in Burkina Faso. *Arid Soil Res. Rehabil., 13*(4), 343–355. https://doi.org/10.1080/089030699263230

Sawadogo, M., Somda, J., Seynou, O., Zabré, S., & Nianogo, A. J. (2011). Catalogue des bonnes pratiques d'adaptation aux risques climatiques au Burkina Faso. UICN *IUCN* (International Union for Conservation of Nature) Burkina Faso.

Schuler, J., Voss, A. K., Ndah, H. T., Traore, K., & De Graaff, J. (2016). A socioeconomic analysis of the zaï farming practice in northern Burkina Faso. *Agroecol. Sustain. Food Syst., 40*(9), 988–1007.

Snell, M. (2011). *Cost–benefit analysis*. Thomas Telford Ltd.

Suo, X., & Cao, S. (2021). China's three north shelter forest program: Cost–benefit analysis and policy implications. *Environ. Dev. Sustain., 23*(10), 14605–14618. https://doi.org/10.1007/s10668-021-01260-z

RGPH (Cinquième Recensement Général de la Population et de l'Habitation du Burkina Faso- Fifth General Census of Population and Housing in Burkina Faso), 2022. Retrieved from: https://www.insd.bf/fr/resultats. Accessed April 15, 2024.

Verdone, M. (2015). *A cost-benefit framework for analyzing forest landscape restoration decisions*. Gland, Switzerland: IUCN (International Union for Conservation of Nature).

Wild, R., & Walters, G. (2022). The forest is clothing for the ancestors: A rapid cultural assessment tool for forest landscape restoration policy processes. *For. Ecol. Manage., 504*, Article 119825. https://doi.org/10.1016/j.foreco.2021.119825

WOCAT-World Overview of Conservation Approaches and Technologies. Retrieved from https://www.eld-initiative.org/en/country-work/africa. Accessed May 20, 2024.

Yirdaw, E., Tigabu, M., & Monge Monge, A. A. (2017). Rehabilitation of degraded dryland ecosystems-review. *Silva Fennica, 51(1B)*, Article 1673. doi: 10.14214/sf.1673.