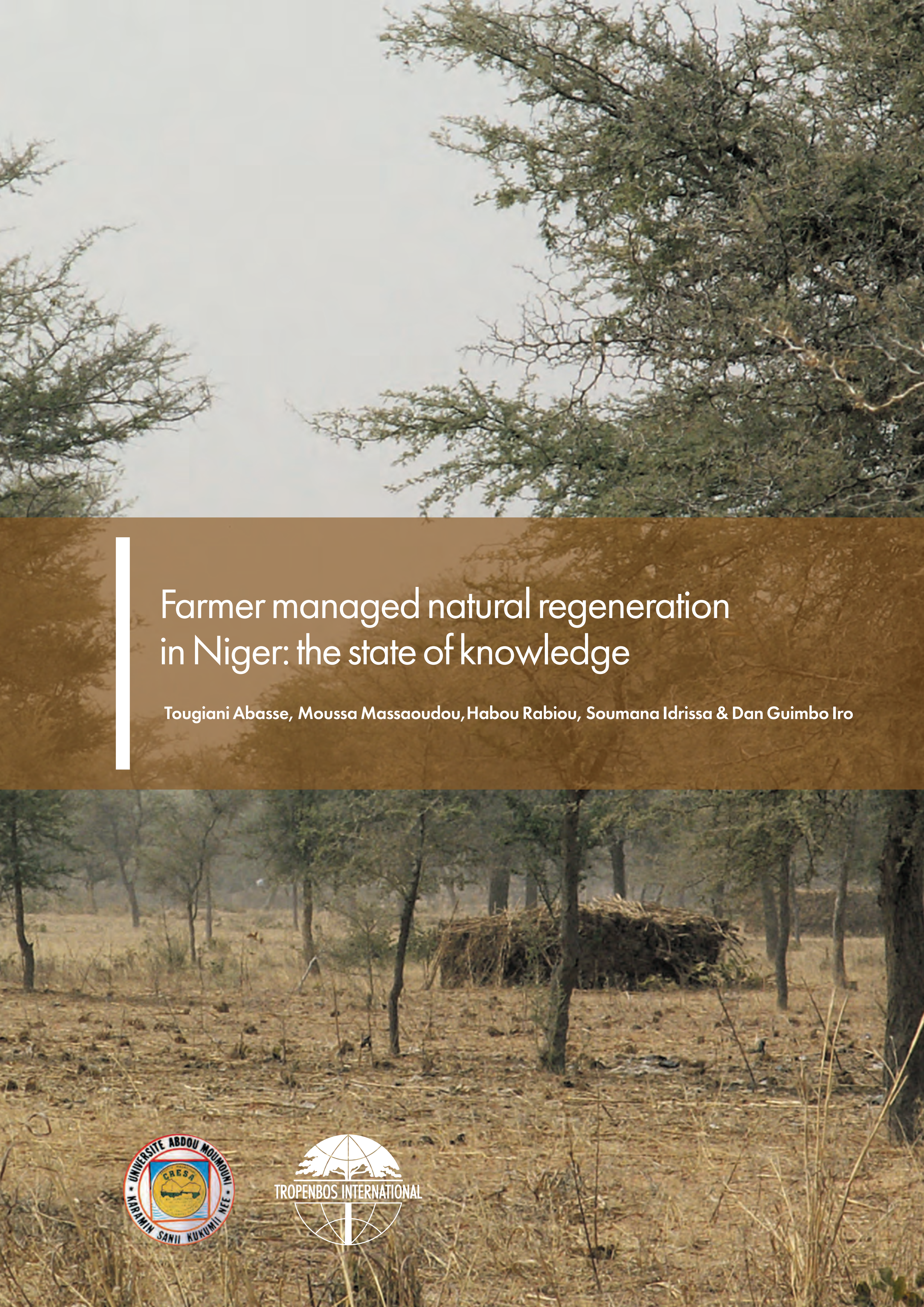

Farmer managed natural regeneration in Niger: the state of knowledge

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Cover photo: Young, dense agroforestry parkland dominated by *Faidherbia albida* just after harvesting a good crop of millet. Photo: Chris Reij

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2023

Livestock in an agroforestry parkland dominated by *Faidherbia albida* (Zinder region). Although it is after the harvest, the goats are tethered and not grazing uncontrolled. Photo:Chris Reij

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Farmer in the Zinder region harvested ficus leaves for his nine sheep. Before the emergence of FMNR he did not have any livestock. Photo: Chris Reij

Summary

Faced with environmental degradation and strong land pressure, farmers in densely populated areas and especially in south-central Niger, have intensified their agricultural production systems. They have done so by increasing the number of trees and shrubs on their fields, and thus have created new agroforestry parklands whose scale in – the regions of Zinder, Maradi and Tahoua is about 5 million hectares (Cotillon *et al.,* 2021).

This scale of regreening is not based on tree planting. Rather, since the mid-1980s farmers have protected and managed the natural regeneration of trees and shrubs on their croplands. Many studies show that farmer managed natural regeneration (FMNR), has increased crop yields from 31 to 350 kg/ha in some studies and provided family food security, even in drought years. But cereal yields still remain low and will not be sufficient to feed a rapidly growing population.

Studies also show that through the sale of fuelwood and service wood, FMNR increases the income of all social categories, even the vulnerable and very vulnerable (men, women and youth). The pruning of trees in the fields has also reduced the distances travelled by women to collect fuelwood. FMNR has also increased the availability of browse fodder to farmers and agropastoralists, with households practising FMNR harvesting 30-45 kg of browse per day. Economists have not yet been able to express the multiple impacts in monetary terms, but studies on the costs and benefits of FMNR all indicate that it is economically rational to invest resources in this practise (4.6). The costs are modest (no equipment and little labour), and the benefits are substantial. As a consequence, tree cover has been sustained without external incentives (e.g. food or cash-for-work), an outcome that distinguishes FMNR from large-scale tree planting projects where farmers'stewardship ended when the external incentives ended.

Agroforestry landscapes are being created at scale due to decisions made by a few hundred thousand individual farmers. A study comparing tree densities in the south-central regions found that on 2% of the area there was a slight decrease in densities between 2005 and 2014, but on 23% there was a significant increase during the same period (Cotillon et al., 2021). Increasing the number of trees and shrubs per hectare has increased litter production. This improves the soil structure and allows greater quantities of water to be stored. However, the addition of litter also contributes to improving soil fertility. Several studies have shown that trees can significantly improve the chemical fertility of soils as well as set the stage for greater intensification through judicious use of mineral fertilizer. Certain species, which often dominate regeneration such as *Piliostigma reticulatum*, *Guiera senegalensis* and *Combretum glutinosum* have a positive impact on the content of chemical elements (carbon, nitrogen and available phosphorus).

There is not yet sufficient data on the amount of carbon sequestered by agroforestry parklands in Niger, but it is certainly at least 30 million tonnes – (5 million hectares multiplied by an average of 6 tonnes per hectare). There are data on carbon stocks in the above-ground part of trees for some

species (table 8) but not on the amount of carbon in root systems, which in semi-arid areas – can be as substantial as the above-ground stock.

FMNR has enabled village communities to better adapt to climate change and build resilience. For example, even if crops fail, farmers can cut some trees and sell them at the market as fuelwood or service wood, which provides revenue to buy grain. FMNR also has a positive impact on crop yields, even in years of poor rainfall. A study showed that in 2011 (a drought year), the department of Kantché (Zinder Region) produced a cereal surplus of almost 13,000 tonnes. This department is characterised by a high population density (over 100 people per hectare), but also by high tree densities.

Since the late 1980s, farmers began to perceive that they had a right to the trees on their own farms. This perception led to increased participation of local communities in the management of their natural resources, which was reinforced by the state's decentralisation policy. Thus forestry policy has evolved from the exclusive management of trees by the state (1960-1980) to a presidential decree issued on 30 July, 2020, which recognises that planted or regenerated trees belong to the producer. This will help encourage farmers to invest more voluntarily in trees on their fields, and will improve the future prospects of young people.

1. Introduction

1.1 Context

Niger is the third largest landlocked country in West Africa with an annual population growth rate of 3.9% (Charbit and Becker, 2022), doubling in less than 20 years (CILSS, 2016). Agriculture is the main economic activity, employing more than 80% of the population. This sector accounts for more than 23% of GDP (INS, 2019). Agriculture is essentially rainfed, dominated by cereals (millet, sorghum) and some cash crops (groundnuts, cowpeas).

The natural resources that form the basis of agro-sylvo-pastoral production are undergoing intense degradation as a result of climatic and anthropogenic factors (Rognon, 2007; Baggnian *et al.*, 2014). Indeed, this part of the Sahel has experienced a series of droughts and food crises (Ozer *et al.*, 2010; Zakari *et al.*, 2016; Tahirou *et al.*, 2019) which are the result of a combination of factors, the most important of which are the trends towards a drier climate and strong demographic growth. High demographic pressure has eliminated the possibility of leaving fields fallow to restore their fertility, and for decades the policy of agricultural modernization has focused on improved varieties and the use of inputs without recognizing the fundamental role of 'agroforestry' (Mamoudou, 2010; Karimou Barké *et al.*, 2015; Reij and Winterbottom, 2015). The combination of these factors has inevitably led to the modification of ecological balances and land degradation (Tappan and McGahuey, 2007; Ambouta *et al.*, 2009; Herrmann and Tappan, 2013).

These climatic and anthropogenic constraints have led to a considerable decrease in crop yields as a result of reduced soil fertility due to the loss of vegetation cover and topsoil. The wind at the beginning of the rainy season buries the young crops and limits seed germination, thus leading to the need to reseed or replant farmers' fields, which disrupts the cropping calendar (PPILDA, 2005). Without the protection of trees, crops are exposed to the effects of erosion. Farmers have had to reseed three, four and sometimes five times in the same year to be able to produce (Rinaudo, 2007).

The rapid population growth observed in recent decades has not kept pace with agricultural yields in Niger (FAO, 2003). This situation has led to the expansion of agriculture into marginal lands (Hamidou *et al.*, 2014; Badji *et al.*, 2015; Zakari *et al.*, 2016) and to the increase in pressure on land through overgrazing and deforestation (Dutordoir, 2006; Bationo *et al.*, 2012; Karimou Barké *et al.*, 2015). Indeed, there is now a general decline in soil fertility (Ambouta *et al.*, 1998), the disappearance of fallow land and the overexploitation of woody resources (FAO, 2003; Ozer *et al.*, 2010). Thus, agriculture is evolving in a context of low productivity due to poor soils and a very unfavourable climate, and especially the insufficiency and poor spatio-temporal distribution of rainfall; (Zakari *et al.*, 2016).

In Niger, with the high cost of fertilizers and the gradual disappearance of fallow land, farmers have questioned certain practises that undermine the productive potential of the environment, such as the radical elimination of woody plants before the start of the dry season. This practise is increasingly replaced by the preservation and encouraged regeneration of trees and shrubs, which is done systematically in the fields (Adam *et al.*, 2006; Danguimbo, 2011). This practise of farmer-managed natural regeneration (FMNR) was introduced in Niger by the Maradi Integrated Development Project. From 1984 onwards, the project encouraged farmers to protect and manage the natural regeneration of trees and shrubs instead of clearing their fields. Farmers quickly realised the multiple impacts, and this simple and effective technique has been adopted over the years by hundreds of thousands of farmers. The adoption process was largely spontaneous. A big advantage of trhe technique is that it does not require the purchase of inputs and produces results relatively quickly (Reij *et al.*, 2009; Lawali *et al.*, 2018). Farmers increase the density of trees and shrubs in their fields, especially in areas with high population densities, supporting the observation and motto of "more people, more trees".

1.2 What is farmer-managed natural regeneration?

FMNR is an agroforestry practise that consists of protecting and managing the natural regrowth (shoots) produced by tree and shrub stumps in the field. It refers to a method of spontaneous reproduction of plants either by seed or vegetatively from stump sprouts. Farmers deliberately select woody plants during crop clearing and field preparation for a variety of purposes.

Figure 1. High density FMNR in southern Zinder dominated by *Faidherbia albida*. Smallholder farmers determine which tree densities on their fields fits them. They often want high densities of Faidherbia albida because of its positive impact on soil fertility and its pods and leaves are used as fodder. Photo:Chris Reij

FMNR is based on the maintenance and protection of existing stumps (Rinaudo, 2010; Tougiani, *et al.*, 2009). It is a farmer-appropriated innovation that responds to the prisms of climate-smart agriculture in the Sahel, particularly that of climate change adaptation and mitigation (Weston *et al.*, 2015; Ado *et al.*, 2019). FMNR has resulted in the regreening of about 5 million hectares in south-central Niger (Reij *et al.*, 2009; Baggnian *et al.*, 2013). Reij *et al.* (2009) that farmers in Maradi and Zinder Regions have added about 200 million trees to their production systems. Given that at least some farmers have continued to increase the number of trees in their fields and that FMNR has been adopted outside of south-central Niger, it is clear that the number of trees on cultivated land has increased, but it is difficult to make a reliable estimate. These trees offer local people the opportunity to exploit woody forest products (fuelwood, service wood and timber) and non-woody forest products (leaves, fruits, bark and processed products). These products are used in food and feed, in pharmacopeia and also as farming tools and household utensils (Reij *et al.*, 2015; Belem *et al.*, 2017; Lawali *et al.*, 2018). It has also contributed to the improvement of cereal production (Haglund *et al.*, 2011). Reij *et al* (2009) estimate that FMNR has increased yields by an average of 100 kg/ha over an area of 5 million hectares (see also sections 3 and 4).

To make production sustainable on land that is exploited for increasingly long periods, the protection of trees in the fields is an ideal option because of the ecosystem services it provides (Larwanou *et al.*, 2010; Baggnian *et al.*, 2014; Bayala *et al.*, 2014).

FMNR is one of the most promising practises for restoring the productive capacity of land in the Sahelian region, improving food security and the resilience of populations to climate hazards. The overall objective of this study is to capitalise on the socio-economic and biophysical impacts of FMNR. Especially since 2009, Nigerien researchers have produced a number of theses and other scientific publications on the impacts of FMNR, which are not always accessible and therefore not well known. The Global Center on Adaptation's "State and Trends in Adaptation Report 2022" notes that FMNR is practised by farmers in the Sahel, but that its impacts are not yet confirmed by research. It is important to fill this gap. This report is a step in this direction.

1.3 The origin of FMNR

In the 1980s, conventional western forestry methods were applied in the Sahel. The standard practise was to create nurseries to produce seedlings of exotic tree species that were planted to combat desertification. In Niger, reforestation was mainly done with exotic species, e.g. *Eucalyptus* spp. and *Azadirachta indica*) to the detriment of local trees and shrubs that were considered as "useless" scrub. Seedlings were also planted in fields containing living stumps of native species.

This was a huge oversight or misunderstanding. In fact, these living stumps represent a vast "hidden forest", just waiting for a little encouragement to grow and offer multiple benefits at little or no cost. These stumps can produce 10 or more stems each. In traditional field preparation, farmers treated these stems as weeds, cutting and burning them before planting their food crops. Under this management system, the stems rarely grew beyond 1.5 metres in height before being cut again. The net result was a barren landscape with few mature trees remaining. Each year, scattered shoots grew, but they were not allowed to grow to their full height because of the standard practise of slash-and-burn cultivation. As a result, forestry officials did not recognize that these shrubs were in fact felled trees with the capacity to regenerate. To the casual observer, the land appeared to be turning into a desert, and observers concluded that tree planting was necessary to restore it.

In 1983, for the first time, Australian agronomist Tony Rinaudo saw what had been there all along – not insignificant desert shrubs, but a "forest of fallen trees", whose stumps were growing back (Rinaudo

2010). The discovery of this hidden forest changed the approach to reforestation in Niger. Farmer-managed natural regeneration (FMNR) is the systematic regeneration of this 'hidden forest'. The desired tree stumps are selected. For each stump, a decision is made as to how many stems will be selected for retention. The tallest and straightest stems are selected and side branches removed to about half the height of the stem. The remaining stems are then cut back.

A first project to promote FMNR started in 1983, in the department of Maradi. Twenty years later, FMNR was already being practised in one form or another across Niger. The practise of FMNR can accelerate the recolonization of species of interest in the field (Larwanou *et al*. 2006; Tougiani *et al*., 2009). This agroforestry technique consists of protecting and managing the natural regrowth on farmland. This natural regrowth is produced by tree and shrub stumps in the field, but also on the germination of seeds of trees and shrubs stored in the topsoil. FMNR consists of "leaving one to three shoots of different trees and shrubs to continue their growth during clearing (in the dry season or at the beginning of the rainy season). The tallest and straightest stems are selected and side branches removed to about half the height of the stem. The remaining stems are then cut back.

Other authors speak of FMNR "when farmers actively protect and manage regrowth in their fields to (re)create woody vegetation. Usually it involves local species of economic value". FMNR therefore consists of "not uprooting, burning or cutting down shrubs during field preparation for cultivation and during weeding; but also managing the offshoots from the stumps of protected woody plants" (Bonkano, 2005). According to the different definitions, the term has evolved, but the focus remains on increasing the number of trees in agrarian landscapes.

Figure 2. Stem selection of *Guiera senegalensis* during training in FMNR techniques. Photo:Chris Reij

2. Regreening challenges in Niger

The regreening and restoration of the productive capacity of land in Niger is facing major challenges: (i) demographic growth, (ii) more livestock, (iii) climate change, (iv) weak local governance of natural resources, (v) interactions between ecosystem challenges, and (vi) institutional challenges of land restoration in Niger.

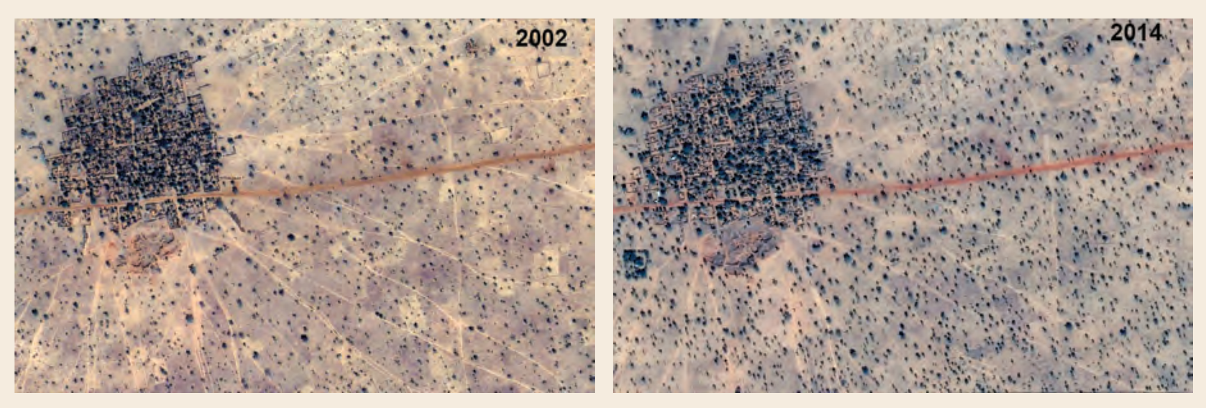
2.1 Population growth and ecosystems

In the regions of Maradi and Zinder between 1977 and 2012, the population increased from 950,000 to 3,400,000 and from 1,002,000 to 3,540,000 respectively (INS, 2015). This shows that the population of these two regions has increased by 350% in 35 years. Population projections from 2017 predict an almost tripling of Niger's population by 2045 (INS, 2018).

This sharp increase in the population results in increased needs for food and basic social services (education, health, water). In addition, access to natural resources will become even more difficult and conflicts between actors may increase. The increase in human population densities is accompanied by an increase in the need for wood for energy and service purposes. These pressures could have led to a reduction in the number of trees and the capacity for natural regeneration. However, over the last 30 years, there has been an increase in tree cover and density. We have witnessed a process of "more people, more trees", while the common perception is that a large increase in population almost automatically translates into a degradation of natural resources. This is not the case in south-central Niger, nor is it the case in other semi-arid and sub-humid regions in Africa (Pasiecznik and Reij, 2020).

How can this large-scale regreening process in south-central Niger be explained? It seems that faced with the crisis in agriculture (declining soil fertility and yields) and the environment (disappearance of natural vegetation and heavy erosion) in the 1970s and 1980s, farmers had no choice but to intensify agriculture or abandon their villages. Increasing the number of trees and shrubs on cultivated land allowed them to solve several problems at the same time: maintaining and improving soil fertility, protecting crops from wind and sun and growing wood on their fields.

Population growth will continue in the coming years, but will farmers continue to increase the number of trees in their fields (densification), and will they increase the number of species (diversification)? Our hypothesis is that farmers will continue to increase the density of trees in their fields, as this will allow them to intensify their production system through the integration of agriculture, forestry and livestock. It is certain that demographic pressure will accelerate the competitive use of space, further accentuating a multi-use of natural resources already under pressure by the effects of climate change.



Figures 3 and 4. Comparison of satellite images of the village of Mazanya (31 km southeast of Matameye, Zinder) taken in 2002 and 2014, with many more trees in the fields. Source: DigitalGlobe.

2.2 Increased livestock numbers

Local livestock and transhumant herds constitute an additional pressure on natural resources (water, pasture and land) already strained by demographic growth (extension of crop fields, overexploitation of agricultural land and forest resources) and the effects of climate. Indeed, the livestock population in all regions of Niger continues to increase (Table 1). A diagnosis revealed that the herbaceous fodder balance at the regional level is still deficient (INS, 2018), even though the dispersal of plant seeds by animals and the increase in the use of organic manure in the fields are increasing, favouring plant regeneration. The prolonged presence of livestock in an area already weakened by human activities leads to overgrazing.

The drop in rainfall has accentuated the deficit in fodder production and reduced natural watering points for livestock. Forage trees and shrubs are pruned by herders to compensate for forage deficits. This allows the animals to get through periods of fodder deficit without considerable weight loss. Increasing the density of trees in the landscape improves fodder availability. Several studies have

Table 1. Evolution of livestock in Niger, 2013-2017 (in thousands of livestock units)

Livestock	2013	2014	2015	2016	2017
Bovins	10,133	11,377	12,059	12,783	13,551
Ovins	10,734	11,108	11,496	11,899	12,316
Caprins	14,310	14,884	15,479	16,098	16,742
Camélins	1,698	1,720	1,743	1,765	1,788
Equins	240	243	246	248	251
Asins	1,697	1,731	1,766	1,801	1,837

Source: INS, 2018

shown the importance of woody fodder during periods of pastoral crisis and fodder deficit (Bognounou *et al.*, 2009). In the dry season, for example, woody stands provide cattle, sheep and goats with the protein and vitamin supplements essential for their survival. Herders make the foliage available to their livestock by pruning or by cutting big branches and tree tops, whch severely damages trees. Thus the increase in tree density is an opportunity to compensate for forage deficits during periods of pastoral crisis.

Figure 5. Livestock growth puts pressure on natural resources. Photo:Chris Reij

2.3 Effects of climate variability

Rainfall in Niger determines four main bioclimatic zones along a decreasing gradient from south to north.

– The Sudanian zone (> 600 mm mean annual rainfall) represents a little less than 1% of the country. It has more or less degraded savannah vegetation. This is the rainfed cultivation zone par excellence.

– The Sahelo-Sudanian zone (300-600 mm mean annual rainfall) covers about 22% of the country. The vegetation is a tree-bush steppe with edaphic formations in western Niger (tiger bush, patchy bush). Rainfed agriculture is widespread, and rural producers combine it with domestic breeding of small ruminants.

– The Sahelo-Saharan zone has an annual rainfall of between 100 and 300 mm; it represents about 12% of the land area and has very sparse thorny steppe vegetation.

– The Saharan zone represents 65% of the national territory and receives barely 100 mm; agriculture is only possible in the oases, practised intensively around market gardening and date palm cultivation.

Climate variability is manifested in the spatial and temporal irregularities of rainfall. In recent decades, there has been a disruption of rainfall patterns and a significant decline in annual rainfall totals (Figure 6). The Sahel experienced the most significant period of rainfall deficit in the years 1973-1974 and 1984-1985. This reduction in rainfall has had consequences for ecosystems, including a reduction in vegetation cover, a drop in the water table and a drop in agricultural and fodder yields. It has caused humanitarian crises and migratory movements. It has also generated an abundant scientific literature, as well as international programmes to combat desertification (Veron et al., 2006). Since the 1990s, without a return to previous conditions, average annual rainfall has become more abundant (Nicholson, 2005). At the same time, Sahelian vegetation has increased, particularly after the wet years of 1994 and 1999, to the point where it has been possible to speak of a "regreening" of the Sahel, although this appears to be very unevenly distributed spatially, as shown by the analysis of NDVI trends. Whether this greening of the Sahel is explained by an increase in rainfall since the 1990s is discussed elsewhere in this report.

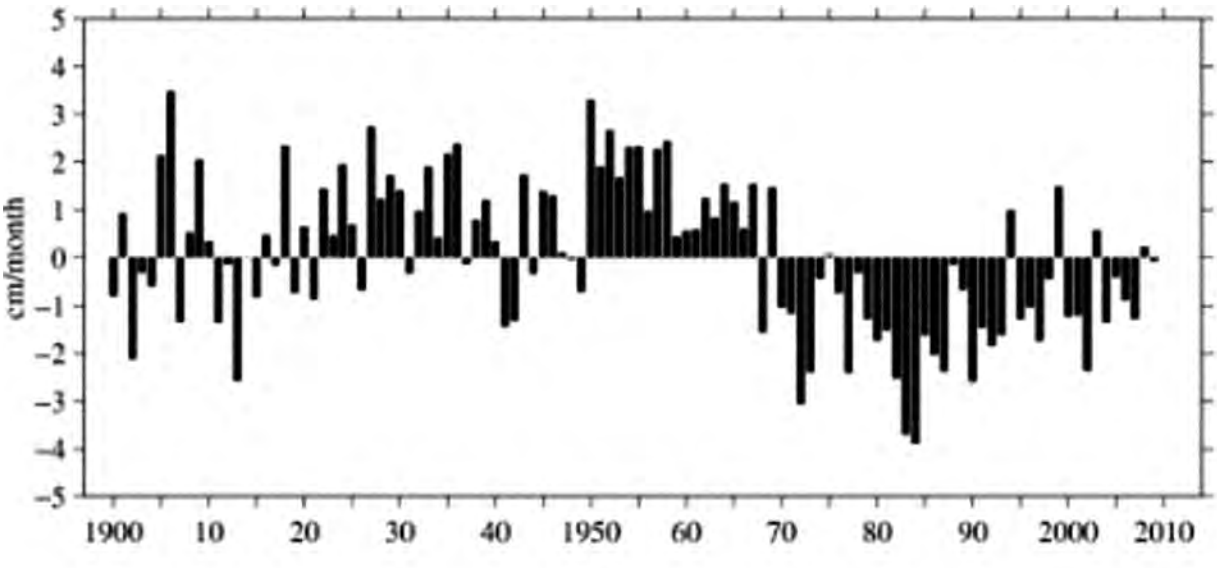


Figure 6. Deviations from the average cumulative wet season rainfall in the Sahel since the beginning of the 20th century (Emeterio *et al.*, 2013).

2.4 Weak local governance

Since the mid-1980s, Niger's policy has been to give communities full responsibility and autonomy in the management of natural resources. However, the transfer of skills from the central to the local level has not yet been completed to allow municipalities to take full responsibility for the management of land resources. This leads to conflicts of authority between the municipalities and the administrative power represented by the technical services and local leaders in the management of natural resources. This limits the involvement of municipalities in restoration actions and land management. The consultation frameworks such as the land commissions (COFO) set up at local levels cannot function without the support of external partners, thus limiting their functionality and the scope of their actions on the ground. These weaknesses and constraints are obstacles to the proper implementation of actions for the restoration and management of natural resources.

2.5 Institutional challenges

The regreening process started in the mid-1980s before the increase in rainfall in a very difficult economic and political context. However, over the years Niger has developed a favourable policy environment with decentralised structures that should ensure the implementation of initiatives to restore the productive capacity of the land. However, there are some challenges, including (i) poor consideration of local experience and know-how, (ii) insufficient coordination between the actors involved in the sustainable management of natural resources, and (iii) poor knowledge of the legal instruments in force in the country and their application, and (iv) a lack of maintenance and ownership of restored land by the beneficiaries, which poses a problem of sustainability.

The problem of sustainability does not arise for two simple techniques. Planting pits or "tassa" which are used to restore denuded land with a hard crust. This technique was introduced in the department of Illéla (Tahoua) in the late 1980s and has been adopted often spontaneously by individual farmers, resulting in the restoration of tens of thousands of hectares in the Tahoua region and elsewhere (Hassane and Reij, 2021). FMNR is the second technique that has been appropriated by farmers since the 1980s, and its diffusion has enabled landscape transformation on a scale of millions of hectares, which is unique in Africa. The following sections review the multiple impacts of regreening at the scale of agricultural production systems. This review is based on scientific publications (PhD's, masters, articles in scientific journals, reports published by researchers in the framework of their support to development projects and on the time-series analysis of satellite images, which have made it possible to follow the evolution of tree densities over long periods.

3. The scale and dynamics of FMNR

In this section we present the scale of FMNR, which was determined by analyses of high-resolution satellite images during the period 2004 to 2009 and again in 2017. The results of the analyses were accompanied by multiple field visits to verify these results. A time-series analysis of the satellite images allowed the question to be answered as to whether farmers continued to maintain the tree densities observed in the early 2000s . The conclusion is clear that farmers have continued to maintain tree densities, and in many cases have increased densities significantly. There is no doubt that the massive adoption of FMNR by hundreds of thousands of individual farmers in the south-central region has produced a transformation of the landscape.

3.1 Evolution of vegetation cover in south-central Niger

In Niger, recent studies on FMNR show surprising results in terms of regreening (Rinaudo, 2007; Tougiani *et al.*, 2009; Cotillon *et al.* 2021). Farmers in several densely populated areas of the country are protecting and managing the natural regeneration of trees and shrubs on their farms. The process, initiated since the mid-1980s in Niger, has led to the reconstitution of vegetation on some 5 million hectares of farmland, resulting in a transformation of the environment.

A process of densification of the agroforestry park in south-central Niger

Studies often present tree densities in a few villages in a specific year, but what is the evolution of the number of trees in the villages over a longer period? A few studies have been carried out that rely on time-series analysis of high-resolution satellite images.

The small black spots in these photos (Figures 7 and 8, opposite page) are trees. It is clear that the number of trees in 1975 has decreased, which is not surprising, as the period from 1950 to 1968 was characterised by good rainfall. The 1970s saw a sharp reduction in rainfall and a rapid degradation of the vegetation. The 2005 image shows a much higher number of trees. Judging from the size of the villages, it is obvious that there was a strong growth of the population. Hundreds of images in the regionconfirm this trend.

In 2008, scientists from the U.S. Geological Survey EROS Center developed a practical technique for mapping tree density in the Sahel using high-resolution satellite images (Reij *et al.*, 2009; Cotillon and Mathis, 2016). Figure 8 illustrates different tree densities, which vary from open landscapes with isolated trees to fields with dense vegetation cover (15% to 25%).

Figure 9 shows that 66.6% of cultivated land in Maradi and Zinder regions has trees on it (4.2 million ha), of which 32% is in open landscapes with isolated trees, 23.3% has low vegetation cover, 11% has medium cover and 0.3% has high cover. On average, densities are highest in southern Zinder.

It is important to note here that a field with 40 or even with 100 young trees show a low vegetation cover, but if farmers continue to protect and manage them they will develop a medium density cover. Fields with many young trees don't look impressive, but they are the agroforestry parklands of the future.

To study the dynamics of FMNR in south-central Niger, USGS used the same methodology to estimate tree densities as in 2005 (Figure 10). On 73.3% of cultivated land there is no change in densities between 2005 and 2014. On about 23.1% there are significant increases in tree densities, especially in Magaria, Matameye and Mirriah departments of southern Zinder. Less than 2% of the cultivated land shows insignificant decrease in tree densities (Cotillon *et al.* 2021).

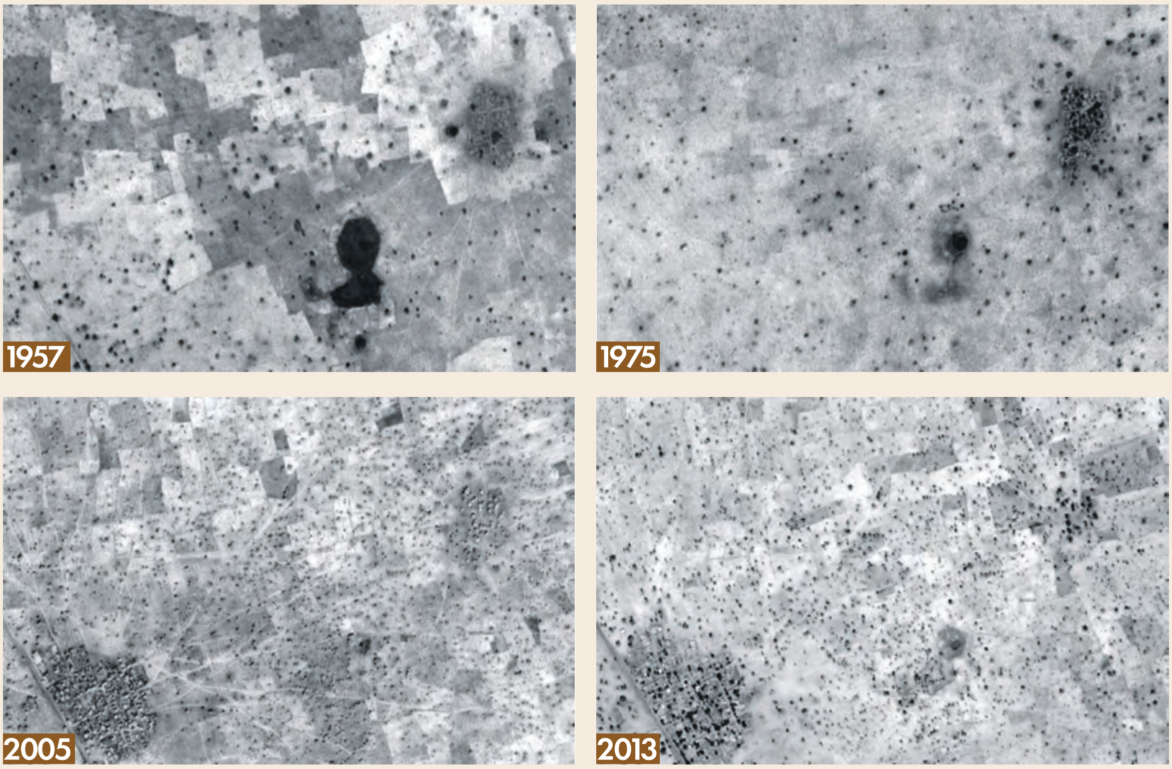


Figure 7. The same village in southern Zinder in 1957, 1975, 2005 and 2013. Source: Reij *et al.* 2009. Image 2013 courtesy Gray Tappan.

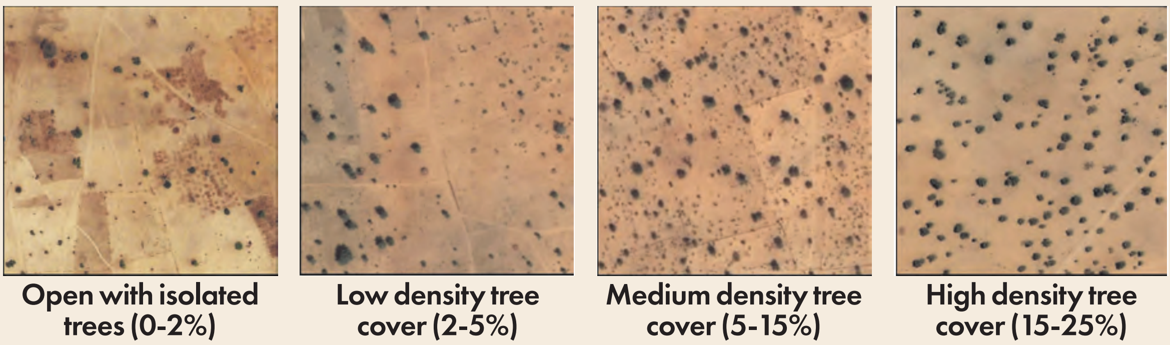


Figure 8. High resolution satellite images showing different tree densities within 10 hectare plots. Source: Cotillon *et al.* 2021

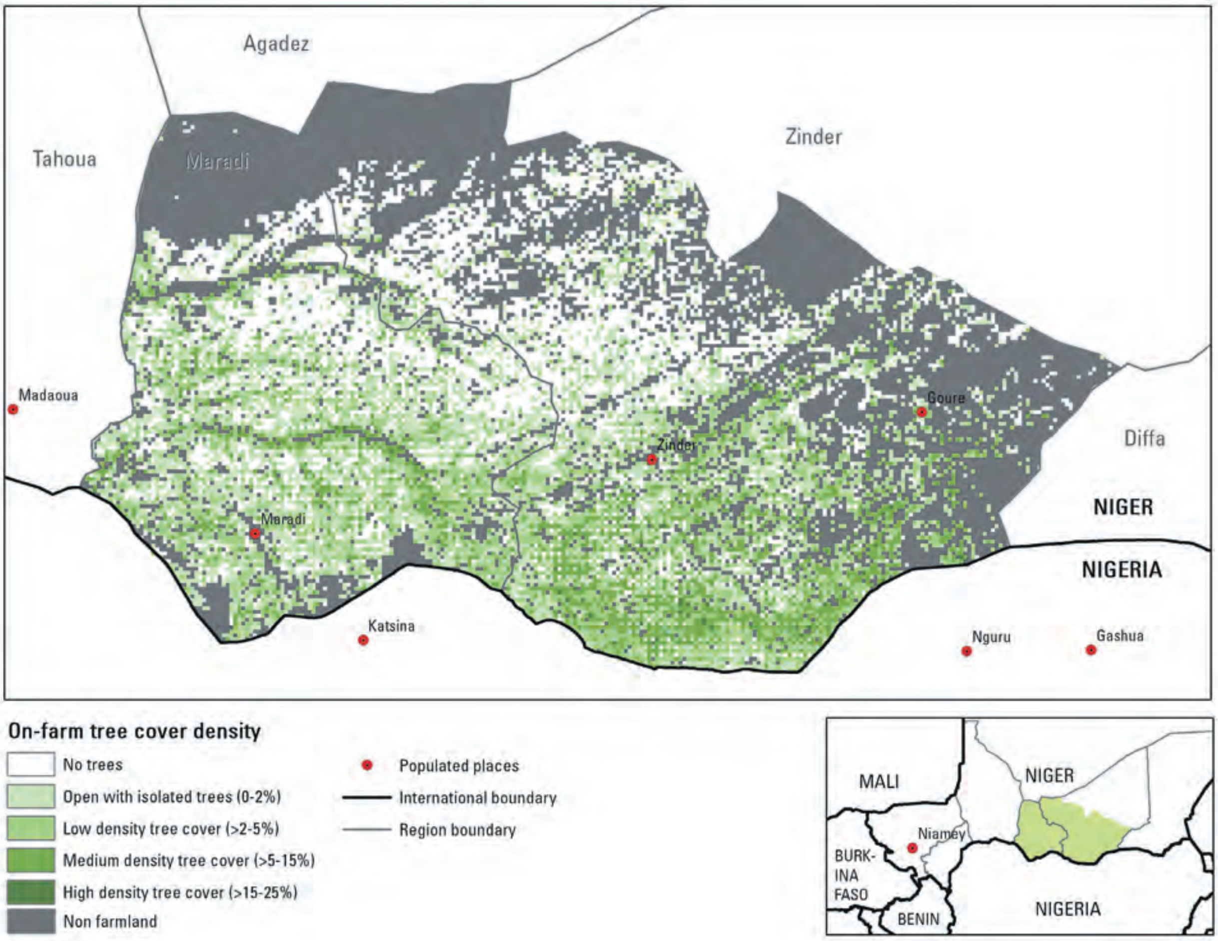


Figure 9. Tree cover on cropland in south-central Niger at 2 km resolution. Source: map produced by US Geological Survey; published in Cotillon *et al.*, 2021.

The high-resolution images in figures 11 and 12 (and Figures 3 and 4) show examples of the increase in tree densities in southern Zinder between 2002 and 2014. The images are taken during the dry season and show quite high densities also in the vicinity of the village. Although the population increased in both cases, the number of trees also increased in the same period (Cotillon *et al.*, 2021). This illustrates the statement "more people, more trees".

Most of the new agroforestry parklands built by farmers remain stable, and on almost a quarter of the area (about 1 million hectares) farmers have continued to increase the density of agroforestry parklands. The few instances of decrease seem to be mainly due to the absence of management committees or to conflicts at the village level.

Overall, the expansion of FMNR practise is the result of the awareness and willingness of people to protect and manage woody species for the benefits of the practise and for their well-being (Zounon 2021). The large scale of landscape transformation in south-central Niger is largely the result of spontaneous adoption of FMNR by farmers who have seen its multiple impacts. However, there are

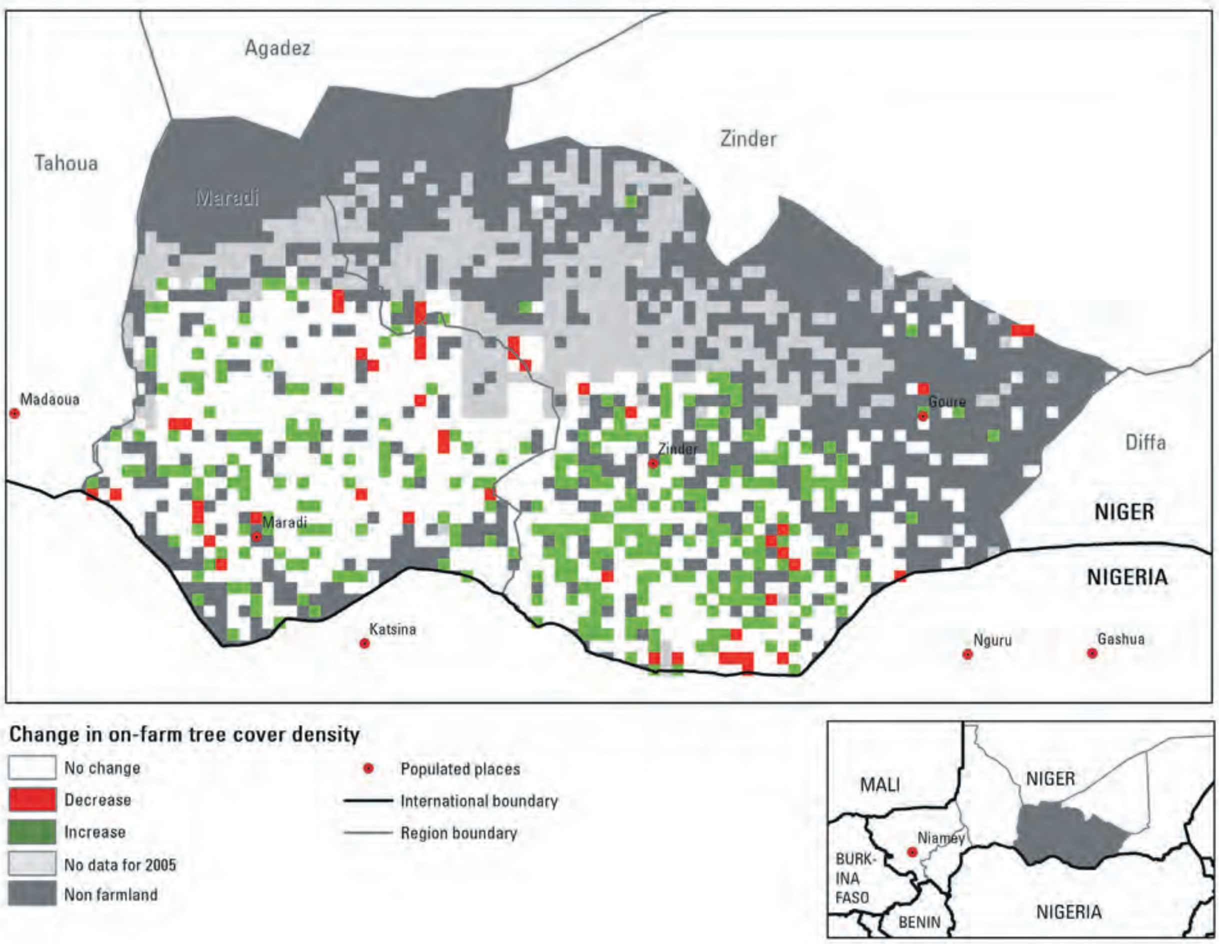
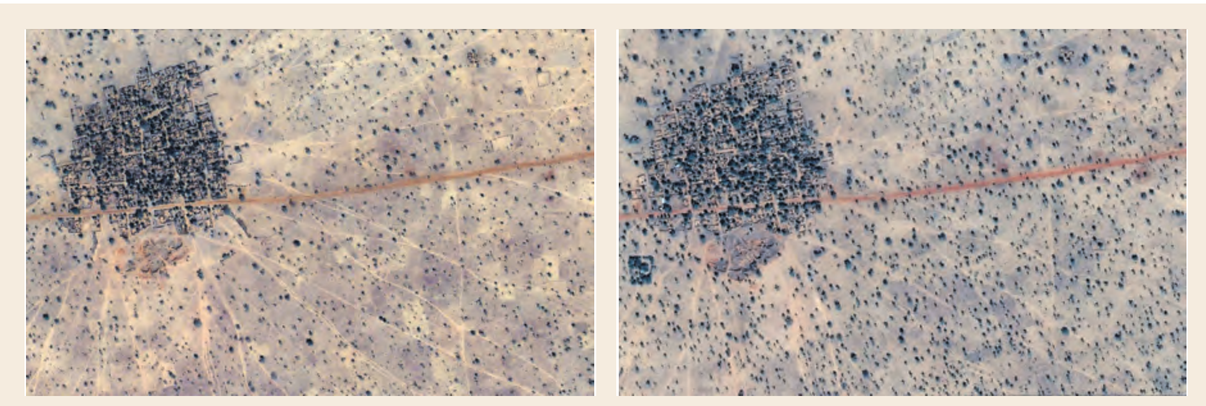


Figure 10. Evolution in tree density on cultivated land between 2005 and 2014 in south Maradi and Zinder regions using a 2-km sample grid and high-resolution satellite images. Map produced by U.S. Geological Survey, later published in Cotillon *et al.*, 2021.



Figures 11 and 12. Comparison of satellite images over a period of 12 years, which show the typical case of increasing tree density in areas that had low densities. Note also the growth of the village and the narrow cattle corridor in the left and lower parts of both images. This village is located 23 km south of Matameye. Dates of the images: left - 7 March 2002; and right - 13 January 2014. Source: DigitalGlobe.

interventions by non-governmental organizations (NGOs) and projects supported by environmental services, which have promoted FMNR and thus supported the process of diffusion and establishment (Baggnian *et al*, 2013).

The adoption of FMNR is related to the level of education of household heads. Marou et al. (2002) had already indicated that household education is a determining factor in the adoption of this practise. The gradual adoption of this technique by farmers has led to a dramatic recovery of vegetation in the area and this process continues (Reij and Winterbottom, 2015).

Let us now look at the structure of the new agroforestry parklands. The survey results show variations in the composition of woody vegetation.

3.2 Characterization of woody vegetation structure

The composition and structure of woody vegetation vary considerably from one locality to another depending on environmental factors and anthropic disturbances (Ouédraogo 2006). Zounon (2021) revealed, following research in the Maradi region, 21 species grouped in 12 families in the central Sahelian zone, 35 species divided into 17 families in the Sahelo-Sudanian zone and finally 24 species divided into 14 families in the northern Sudanian zone. The most dominant families are the Capparaceae and Combretaceae at all sites. Baggnian et al, (2014) found a juvenile flora containing 38 woody species belonging to 22 families at the sites of Dan Saga (Maradi), Elgueza, Daré, Zedrawa and Ara Sofoua (Zinder).

Guiera senegalensis and *Combretum glutinosum* have a relatively good suckering capacity and this mode of asexual reproduction may account for the demographic structure of juvenile populations (Baggnian *et al*, 2014). Each plant species is distributed according to its own tolerance to the multitudes of factors that comprise its environment (Tremblay *et al.*, 2002). The selection of species by farmers is guided by their capacity to regenerate and their usefulness in terms of uses and service provision (Akpo *et al.*, 2003). Ouédraogo (2006) states that in an human-modified environment, characterised by an extensive land use system, the future of certain species depends on the types of maintenance or protection. Baggnian *et al* (2014) showed that in the Zinder region, *Faidherbia albida* is the only species with a fairly good regeneration capacity. This species is protected and spared from any form of anarchic exploitation because it has certain qualities in the eyes of the population. The roles of certain species in the restoration of the ecological balance and social and economic life give them a privilege of deliberate preservation (Abdoulaye and Ibro, 2006).

The regeneration potential of woody plants is based mainly on the survival rate of seedlings during their development phase. The demographic structure of juveniles reveals three (3) main phases (Ouédraogo *et al.*, 2009). In the initial phase, there is an establishment and good development of juveniles which takes place in the [0-0.5 m[class. The second and most critical phase is characterised by a very low survival rate of the populations which occurs during the transition from the stratum [0-0.5 m[to [0.5-1 m[. The third phase of dynamics is characterised by the stabilisation of the survival rate from the [0.5-1 m] stratum to the upper strata. Tree regeneration processes can be influenced by factors such as dispersal pattern, viability, dormancy and seed predation (Khurana and Singh, 2001), water stress, soil structure, temperature, insect attacks, and grazing that can delay the transition from juvenile to shrub stage (Bationo *et al.*, 2001).

The average tree density differs from one village to another. Indeed, fairly low densities are observed in the village of Kirou-Haoussa (40 trees/ha), in Zedrawa (32 trees/ha) and in Daré (57 trees/ha). These average densities are lower than those obtained by ROSELT in the Department of Aguié (80 plants/ha). The fields of the very vulnerable (29 ft/ha) and moderately vulnerable (42 ft/ha) have fewer trees than those of the less vulnerable (59 ft/ha) and extremely vulnerable (50 ft/ha). It is interesting to note that the extremely vulnerable ones have relatively high densities.

The density of trees also varies according to the distance of the field from the village. Thus, the hut fields (closer to the village) are characterised by the presence of very old trees with a low density, whereas in the fields further away (up to 1000 m from the village), there is a high density of young trees. A study carried out in Magaria in two (2) village areas of Ara Sofoua and Ganaoua, lists the woody species and shows this biological diversity (Adamou, 2009). Indeed, 68 woody species were identified in the Ara Sofoua area and 40 woody species in the Gaounawa area (Table 2).

These different species are distributed in increasing numbers as one moves away from the houses (from the hut fields to the distant fields). In Ara Sofoua, the number of trees inventoried varies from 206 trees/ha (15 species) in the hut fields to 445 trees/ha (27 species) in the medium distance fields and 685 trees/ha (34 species) in the distance fields. The most frequent species in the *terroir* are: *Faidherbia albida*, (33%) *Piliostigma reticulatum*, (24%) *Hyphaene thebaïca* and secondarily *Annona senegalensis*, *Phoenix dactylifera*, *Prosopis africana*, *Guiera senegalensis*. In the Gaounawa area, there are 373 plants/ha (16 species) in the hut fields, 266 plants/ha (12 species) in the medium distance fields and 428 plants/ha (39 species) in the distant fields. The predominant species are: *Faidherbia albida*, *Anona senegalensis*, *Piliostigma reticulatum*, *Guiera senegalensis*, *Hyphaene thebaïca*. The density of *Faidherbia albida* in this area is 136 plants/ha. The main woody species more frequently used by farmers are also those with good natural regeneration.

The table (see over, page 18) prompts two observations. Firstly, it is interesting to see that the average tree density in Dan Saga, considered the flagship FMNR village, was lower in 2009 than the average density in the other five villages in the table. Secondly, it is remarkable that the density of trees increases as one moves away from the village, i.e. in the distant fields. It is remarkable that farmers are investing in agricultural intensification on the more remote fields. Researchers at ORSTOM (now IRD) have always found that farmers intensify mainly on the fields close to their homes and that agriculture becomes more extensive when moving away from the village. Dan Saga had an average density of 74 trees/hectare in 2009, but Rabiou *et al.* (2020) report an average density of 153 trees/hectare in this village just 10 years later. The phenomenon of protection and management of natural regeneration is older in the villages of the Zinder region, where customary legislation in Damagaram prohibited the felling of a *Faidherbia albida* tree at the risk of decapitation.

The analysis of satellite images in combination with numerous field visits leave no doubt that farmers in south-central Niger have invested in FMNR and that their individual decisions have produced a transformation of the landscape. What was their motivation? In the 1970s and 1980s, farmers found themselves with their backs against the wall because of years of drought, very low crop yields,

Table 2. Average density of woody plants and dominant species according to villages in three zones

Villages	Average density of woody plants(stems/ha)				Dominant species, in decreasing order of dominance
	1st halo	2nd halo	3rd halo	Total density	
Dan Saga	50	68	103	74	*Combretum glutinosum, Piliostigma reticulatum, Guiera senegalensis, Faidherbia albida*
Dogarawa	55	78	113	82	*Combretum glutinosum, Piliostigma reticulatum, Guiera senegalensis, Faidherbia albida*
Elguéza	33	72	73	60	*Hyphaene thebaïca, Prosopis africana, Piliostigma reticulatum, Faidherbia albida*
Yadagamo	42	91	99	78	*Prosopis africana, Piliostigma reticulatum, Faidherbia albida*
Gaounawa	233	222	458	304	*Faidherbia albida, Annona senegalensis, Piliostigma reticulatum*
Ara Sofoua	206	445	428	360	*Faidherbia albida, Piliostigma reticulatum, Hyphaene thebaïca*

Source: Adamou, 2009

impoverished soils and the disappearance of natural vegetation. This also made life difficult for women who had to walk 2 to 3 hours every day to collect firewood. They had to act or leave the village. Increasing the number of trees in their fields solved several problems: intensification of agriculture without buying inputs, maintaining and increasing soil fertility, adaptation to climate change and increasing the availability of fuelwood.

3.3 Increased rainfall or change in human management?

Is the regreening linked to a return of rain since the 1990s, or are there other explanations? It is likely that an increase in rainfall facilitates a regreening process, but this process began in south-central Niger in the mid-1980s before the return of rain. Figures 13 and 14 are part of a mid-2000s transect of 57 km, starting 19 km north of the Niger-Nigeria border in south Zinder and ending 37 km south of the border. Figures 15 and 16 show two villages on either side of the Niger-Nigeria border in January 2022. These 4 photos illustrate that there are strong differences in tree densities on both sides of the border.

If rainfall is a determining factor in regreening, northern Nigeria should have about the same density of trees as southern Niger. The Hausa live on both sides of the border, the same population density, with the same soil types. As one progresses a little farther south of the border, the rainfall increases slightly. The conclusion is not that rainfall does not play a role in the regreening process, but that human management of the trees is a more determining factor. How to explain the low tree densities in northern Nigeria? There have not yet been studies to explain this, but our hypothesis is that farmers in this region do not feel that they own the trees on their fields, which is a condition for them to invest in trees.


Figure 13 (left). A village in southern Zinder in the mid-2000s, 8.5 km north of the border with Nigeria.
Figure 14 (right). An almost treeless area 4 km south of the Niger-Nigeria border in the mid-2000s.
Courtesy: Gray Tappan

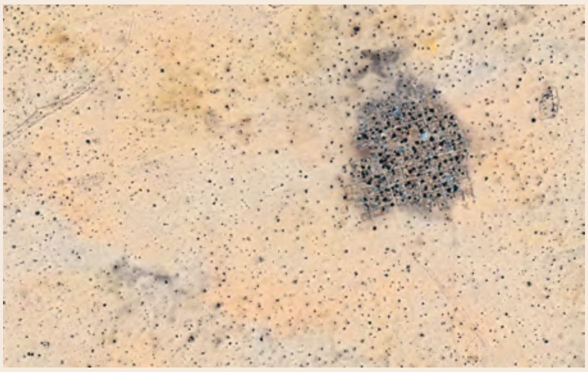



Figure 15 (left). A village in southern Zinder in January 2022, 1.5 km north of the border with Nigeria.
Figure 16 (right). A village in Nigeria in January 2022, 1 km south of the Niger-Nigeria border.
Courtesy: Gray Tappan

4. Socioeconomic impacts

The practise of FMNR developed quickly, particularly in densely populated areas of the Maradi and Zinder Regions. In the 1980s, the populations of these areas faced a food crisis caused by declining soil fertility and an energy crisis, as natural formations had almost disappeared and women had to walk 2 - 3 hours every day to collect fuel for their cooking. Agriculture had to be intensified and the solution was to increase the number of trees on the fields. For them, FMNR was a practical and cheap solution, which did not require the purchase of inputs. In this section we look at some of the socio-economic impacts of FMNR, including its impact on agricultural yields and food security, rural poverty, women, timber production, value chain development and its impact on rural poverty. The last part of this section deals with the costs and benefits of FMNR.

4.1 Agricultural yields and food security

If yields increase, there will be an improvement in food security and a decrease in rural poverty. Reij et al. (2009) estimated that FMNR increased cereal yields by an average of 100 kg/ha. For an area of 5 million hectares of FMNR this would mean an additional production of 500,000 tonnes of cereals, which would feed 2.5 million people. Was the estimate of an increase of 100 kg/ha on average realistic? Research data indicates that this estimate is rather low. Yield increases vary from 120 to 200 kg/ha for FMNR older than 6 years, but depend on the species, their age and the density of trees per hectare. Despite the positive impact of FMNR on agricultural yields, it is clear that agricultural yields in Niger with FMNR and especially without FMNR are too low to ensure food security for a rapidly growing population.

The impact of FMNR on agricultural yields will depend mainly on the impact of trees on soil fertility. Research conducted in different localities on the use of woody species in the fields shows that *Faidherbia albida* and *Hyphaene thebaica* (Moussa, 1996; Dan Lamso *et al.* 2015), *Borassus aethiopum* (Kadadé, 1999) and *Acacia senegal* (Abdou *et al.*, 2013) respond to farmers' concerns to improve soil fertility and agricultural production. To better understand the interactions between shrubs and soils, Dan Lamso *et al.* (2015) conducted research on the effect of *Guiera senegalensis* clumps on soil fertility in the village lands of Maradi. The results highlight a significant improvement in the physico-chemical parameters of soils located near Guiera senegalensis tussocks.

The maintenance and increase of tree species in the fields helps to counteract the decline in soil fertility. According to Giffard (1964), a stand of *Faidherbia albida* with a density of 50 trees/ha would produce 75 kg of nitrogen, 12 kg of phosphorus, 13 kg of potassium, 20 kg of sulphur, 25 kg of magnesium and 120 kg of calcium per year. Indeed, studies in the Dosso region confirm that the annual leaf mass on the ground of a *Faidherbia albida* parkland of 40 to 50 trees per hectare yields 100 kg of nitrogen, 18 kg of calcium, 20 kg of manganese and 2 kg of potassium (Yamba, 1993). This gives *Faidherbia albida* a fertilizing power and a great capacity to fix nitrogen. 40% to 100% of the farmers interviewed reported a quantitative and qualitative improvement in agricultural production thanks to soil fertility through FMNR (Larwanou *et al.*, 2006). Yamba and Sambo (2012) found that farmers increase the number of trees mainly to maintain and improve their soil fertility.

The increase in agricultural yields will of course depend on the tree species, their density and age. Boubé (2009) found an increase in millet yields in the Maradi region from :

- 32 to 165 kg/ha for FMNR less than 3 years old;
- 59 to 221 kg/ha for FMNR of 3 to 6 years;
- 120 to 209 kg/ha for FMNR of more than 6 years.

This substantial increase in millet grain yields is explained by the contribution of organic matter from the trees through the decomposition of litter, and by the benefits of associating woody plants with crops, creating a microclimate favourable to crop development. Other research (Adam *et al.*, 2006) also points to an increase in millet grain yields of 30 to 220 kg/ha depending on the age of the FMNR. It is particularly under a *Faidherbia albida* park that millet yields reach values of 690 kg/ha, compared to control plots that only record average yields of 350 kg/ha. It should be noted here that *Faidherbia albida* dominates the FMNR in southern Zinder on hundreds of thousands of hectares. *Faidherbia albida* has no leaves in the rainy season, which favours agriculture. In the dry season, the tree is green, which creates suitable resting places for animals seeking protection from heat, and falling leaves help to fertilise the soil.

Figure 17. *Faidherbia albida* fixes nitrogen from the air on its root systems, which improves soil fertility and increases crop yields. Photo: Chris Reij

The presence of shrubs in the plots increases the soil moisture around the stumps so that the associated crops can better withstand water stress during their different development stages and complete their maturity cycle. Studies have shown that water deficit during the cycle, especially during the bolting period, affects the number of ears and the fertility of the ears (De Rouw, 2000; Ali Dib *et al.*, 1992). However, it has been established by Dick *et al.* (2009) that shrubs such as *Guiera senegalensis* and *Piliostigma reticulatum* have a positive effect on water availability (through hydraulic lifting) for crops and for water conservation, a precious material in this semi-arid environment.

Louppe (1991) reports higher trends in soil evaporation in bare plots compared to FMNR plots. This result is in line with farmers' perception that FMNR has positive agroecological effects both on soil fertility protection and management and on crop behaviour. This is explained by the fact that the plant biomass left on and in the soil at the time of clearing has an effect on millet yield. A study by Yelemou *et al.* (2007) on farmers' perception of *Piliostigma reticulatum* revealed that 98% of respondents noted better and faster vegetative growth when the crop was mulched with *Piliostigma reticulatum* leaves.

In multispecies stands, some field observations show that *Guiera senegalensis*, *Combretum glutinosum* and *Piliostigma reticulatum* have a positive effect on millet crops. Thus, yields are better on fields benefiting from the presence of woody plants, which allows millet yields varying from 100 to 370 kg/ha, while those on control fields without trees are in the order of 50 to 270 kg/ha.

The consequence of the improved fertility and physical properties of the soil linked to the presence of trees is an increase in crop yields. The presence and management of shrubs in the fields allows a notable improvement in the yield of the associated cereal (Kizito *et al.*, 2006; Abasse *et al.*, 2013; Dossa *et al.*, 2013; Binam *et al.*, 2015).

Increased production increases farmers' resilience in coping strategies. Andres *et al.* (2015) highlighted the impact of FMNR in household resilience in a village terroir (Dargué), rural commune of Chadakori in Guidan Roumdji Department. The assessment of agricultural yields was based on 100 m2 yield squares in FMNR plots and control plots supported by qualitative surveys of family farm production. The increase in agricultural yields was 200 kg/ha.

The combination of assisted natural regeneration plus organic manure plus NPK mineral fertilizer resulted in the highest millet grain and straw yields in the Sahelo-Sudanian zone (464 ±214 kg/ha for grain and 2126 ±1193kg/ha for straw) (Zounon *et al*, 2020).

FMNR has a positive impact on agricultural yields, but what is the situation in a drought year? In 2011 Niger recorded a large cereal deficit due to drought. Yamba and Sambo (2012) conducted a study in two departments in the Zinder Region (Kantché and Mirriah) with very high population densities, but also with high FMNR densities. One of the conclusions was that these departments produced a cereal surplus in 2011. The department of Kantché even had a surplus of almost 13,000 tonnes.

It is acknowledged that FMNR significantly increases crop yields. However, even with FMNR, cereal yields are generally too low to feed a population that is growing at a rate of 3.9% per year.

4.2 Rural poverty

With the practise of FMNR, agro-sylvo-pastoral production has improved as well as the availability of food resources. Studies show that FMNR is practised by all social categories regardless of gender. A study entitled 'Assisted Natural Regeneration (FMNR): a tool for adaptation and resilience of rural households in Aguié, Niger', conducted by Lawali *et al.* (2018), showed that FMNR offers the local population the possibility of producing and exploiting wood resources (fuelwood and service wood) and non-wood products (leaves, fruits, bark and processed products). These products are used for a variety of purposes such as human food, animal feed, traditional pharmacopoeia, farm tools and domestic utensils. Although mostly self-consumed, these products are also a source of substantial income that contributes to improving the living conditions of the population.

Lawali *et al.* (2018) conducted their study in 5 villages and surveyed 99 heads of households. They defined four groups of producers:

– The low-vulnerability (LV): farmers who have a food stock that can cover the whole year and who capitalise more than 10 ha of agricultural land. Large livestock and a family load of more than 10 people.

– The moderately vulnerable (MV): their food availability does not exceed 9 to 10 months, their land area is between 5 and 10 ha and they have 1 to 2 large cattle and a relatively average load of 8 people.

Figure 18. Sale of fuelwood by individual farmers from a *Faidherbia albida* dominated agroforestry parkland in southern Zinder. Photo: Chris Reij

– The very vulnerable (VV): these producers barely have 6 months of consumption given the family load they carry. They have no large livestock, but a few small ruminants.

– The extremely vulnerable (EV): their production does not cover more than one month's consumption and they have access to small plots of land (one hectare or less) through inheritance or rental. They do not own animals and generally engage in straw selling and agricultural wage labour to ensure their families' survival (Lawali *et al.* 2018: 77-78).

Lawali *et al.* 2018 report that the sale of fuelwood from FMNR earns the 99 producers surveyed 375 (€0.57)± 50 FCFA per household, but this average daily income varies between villages. It is interesting to note that daily incomes are much higher in Dan Saga than in the other villages. Dan Saga has a long history of FMNR and the village has a timber market that has been operating for more than 10 years. In Dan Saga the daily income from the sale of fuelwood is 7075 FCFA (€10.8) for the least vulnerable, 12,500 CFA (19 euro) for the medium vulnerable, 2925 FCFA (€4.5) and 1675 FCFA (€2.5) for the extremely vulnerable. These data show that even those in Dan Saga who are considered extremely vulnerable derive a daily income from the sale of fuelwood that is above the poverty line of €2/day.

Another finding is that a male-headed household can have an average of 450 ± 75 FCFA while a female-headed household can only have 250 ± 75 FCFA per day for the sale of fuelwood from FMNR. The less vulnerable are the holders of larger areas of land in this zone. As a result, they exploit more wood. The most vulnerable, on the other hand, only have plots of land whose wood production hardly exceeds their self-consumption.

The conclusion seems justified that both rich and poor farmers are able to meet the fuelwood needs of their families and even earn cash income from the sale of FMNR products.

Reij *et al.* (2009) estimated that farmers in south-central Niger have added 200 million trees to agroforestry parklands. If a single tree would only produce a value of €0.5/year in the form of fuelwood, fodder and impact on agricultural yields, the value of the annual production of the trees represents €100 million, which go directly back to the farmers, either in cash or in kind as agricultural products. This depends of course on the species and its age, but it is clear that the economic and financial value of FMNR in south-central Niger is enormous.

4.3 Women

Wood collection is generally carried out by women for self-consumption. The practise of FMNR has contributed to lightening women's domestic tasks. The average distance travelled by women to obtain fuelwood has decreased considerably with the expansion of FMNR (Larwanou *et al.*, 2012). This is a significant advance for women, especially as the retreat of the bush meant that they sometimes had to make long journeys to obtain fuelwood. It used to take them 2 to 3 hours every day to collect firewood. Now the women collect firewood often at the family fields. Women in Ara Sofoua travel an average distance of 1.75 ± 0.46 km and women in Gaounawa a distance of 3.02 ± 0.8 km (Larwanou *et al.* 2012).

In villages with a reputation for practising FMNR, the exploitation, processing and marketing of FMNR products have empowered women. In fact, several women's groups organised in the form of

Table 3. Distance (km) travelled for wood collection in Ara Sofoua and Gaounawa (Magaria commune, Zinder Region)

	Classes (km)				Average (km)
Ara Sofoua	1.00-1.75	1.75-2.50	2.50-3.25	>3.3.25	1.75 ± 0.46
Proportion (%) of producers	53.4	27.5	18.9	0.2	
Gaounawa	2-3	3-4	4-5	>5	3.02 ± 0.80
Proportion (%) of producers	38.6	46.5	9.6	5.3	

Source: Larwanou *et al.*, 2012

cooperatives carry out processing and sales of products such as oils, soaps, juices and biscuits from various species derived from the FMNR. This is the case, for example, of the women's groups of Dan Saga and Kégil (Lawali *et al.*, 2018; Massaoudou *et al.*, 2020) whose main activity is the processing of *Balanites aegyptiaca* fruits into oil and soap, and *Ziziphus mauritaina* fruits into biscuits (akouri in the Hausa language). In the Dan Saga area, non-timber forest products from FMNR are marketed by all social categories. These products include leaves, fruits and by-products such as ropes, mats, vans, baskets made from *Hyphaene thebaica* leaves, etc. Surveys conducted by Lawali *et al* (2018) on some by-products (oil, soap and honey) show that processing is practised by women. Assisted

Figure 19. Distances travelled by women to collect fuelwood have decreased for women in FMNR areas. Photo:Chris Reij

Figure 20. A woman in the Dan Saga cluster selling soap made from *Balanites aegyptiaca*.
Photo:Chris Reij

natural regeneration (FMNR) has also enabled women to be more or less autonomous during a certain period of the year vis-à-vis men by making expenditures including the purchase of utensils used during various family ceremonies(Berti et Dramé 2008).

In the Dan Saga cluster, the oil and soap produced provide women with an average of 86,500 FCFA/year (€132), i.e. 62,500 FCFA for oil and 24,000 FCFA for soap. The income from this activity is either shared between the women members of the group or used to fatten small ruminants for the group. For example, one woman member of the group said that she bought two goats with the income from the sale of soap and oil.

4.4 Value chain development

FMNR now appears to be a source of income for households. Studies carried out by IFAD in its intervention zone in Maradi provide a better understanding of the economic role played by the exploitation of wood and non-wood forest products from FMNR in promoting the development of income-generating activities for the population, including women and young people; 50% of farms believe that more than a quarter of their income comes from non-timber forest products (NTFPs).

Several products have been cited in the literature as sources of income for populations. These include oils and soaps made from the fines of *Balanites aegyptiaca*, biscuits made from the fruits of *Ziziphus mauritiana*, *Hyphaene thebaica*, etc. In the framework of a scientific partnership with IFAD, a study on the socio-economic impacts of FMNR was conducted in a village in the Maradi region. This study revealed the annual monetary income generated by FMNR in four village terroirs in the Maradi region (HAMISSOU Abdoul-nasser, 2005): €81/ha/year for biomass and €63/ha for wood and €183/ha for food production, which is equivalent to 800 kg of cereals at a rate of €0.23/kg.

Studies conducted by Amadou *et al*, (2005) in the department of Aguié in seven villages of the Dan Saga cluster and in 10 villages in the Goulbi zone of Maradi revealed that annual honey production was respectively 928 and 1988 litres, with estimated market values of 928,000 FCFA (€1417) and 1,988,000 FCFA (€3035), i.e. an average of 1,000 FCFA (€1.52) per litre.

There is a gradual specialisation and gender division in the sale of non-wood products. In general, women are more interested in selling fruits and leaves, and to some extent soap and artisanal oil derived from them, while men prefer to market the more profitable honey. In any case, the sale of non-timber products has favoured the emergence of income-generating activities, especially among women, and is thus becoming an effective tool in the fight against vulnerability, which has a female face.

The sale of service wood and wood by-products is a male activity. As such, the marketing of agricultural tools is generally of interest to the most vulnerable social strata, who thus find a way to minimise their poverty. It is therefore easy to understand why farmers are particularly interested in the sale of service wood and wood by-products (Moussa, 2007). In reality, the added value is to some extent due to the high price of service wood, not to mention the fact that the sector is controlled and locked up by a few operators. The demand for farm tools on the market remains high during the winter season, which contributes to a significant increase in household income.

The work of Lawali *et al* (2018) has already been cited in the section on FMNR and rural poverty. This study showed the income that different categories of households derive from the sale of service wood and fuelwood.

4.5 Animal feed

The animals are fed throughout the rainy season with aerial fodder. Leaves and twigs from the FMNR are the only means of feeding the animals in stalls. In the dry season, woody fodder is used to supplement the animals' diet. The availability of fodder is increased thanks to FMNR, thus contributing to the development of small ruminant farming, especially for the benefit of very vulnerable groups such as women (Larwanou `, 2006). A report by PASADEM (2015) highlights the improved availability of fodder for adopting households, with 30-45kg of fresh fodder per day in the Maigirgui and Tessaoua areas.

The impact of FMNR practise on fodder production is particularly important during the lean season (Ibrahim, 2007). According to this study, the forage species most concerned by natural regeneration are *Guiera senegalensis*, *Piliostigma reticulatum* and *Combretum glutinosum*.

A study by Rabiou (2009) in the department of Aguié (Maradi Region) describes a reduction or even disappearance of transhumance in the area and a tendency to stake animals due to the availability of forage with FMNR. Hassane and Reij (2021) made the same observation in the village of Batodi (Illéla Department; Tahoua Region).

The woody biodiversity of FMNR used in animal production shows a number of families and species cited by the respondents ranging from 10 to 13 depending on the area, while the abundance of species varies from 17 to 33. The results show that the use of FMNR species in livestock production is related to the success of the FMNR practise and the vocation of the livestock production system (Zounon 2021). The FMNR makes it possible to compensate for the fodder deficit caused by the loss of pastoral areas.

Several authors have shown the importance of woody fodder in animal feed during the rainy season, but also during the dry season, during which time the grasses were reduced to straw and had a quantity of digestible nitrogenous matter that tended to be zero. This quantitative or qualitative insufficiency of herbaceous plants is partly compensated by ligneous plants whose nitrogen value is higher (Djimtoloum, 1997).

4.6 Costs and benefits of FMNR

Economics of Land Degradation (ELD, 2019) carried out an analysis of the costs and benefits of FMNR in the village of Malam Kaka in Dakoro department. The situation in this village is not entirely representative for villages with FMNR in south-central Niger. The population density of this village is low (24 people/km2) and FMNR was introduced there quite recently (in 2013). The majority of the villages with FMNR in south-central Niger have much higher population densities (100+ people/km2) and a longer history of FMNR. Our hypothesis is that the costs and benefits of FMNR in these villages will be higher than in Malam Kaka.

Figure 21. Small ruminants fed with aerial fodder in the dry season. Photo: Chris Reij

For an investment of less than 7676 FCFA (€11.7), FMNR in Malam Kaka yields an economic and financial net present value (NPV) of more than 300%, higher than its opportunity cost of 10% (ELD, 2019:9). The NPV is calculated as the sum of the net present benefits, in this case over a period of 20 years. The discount rate used is 10%. This rate reflects that the benefits obtained now are more valuable than those obtained in the future.

In the situation without FMNR there is a density of 14 trees/ha (53% *Faidherbia albida* and 14% *Sclerocarya birrea*) and yields decline by 1%/year due to poor agricultural practises that continuously deplete the soil (ELD, 2019:34). In Malam Kaka the tree density reaches 61/ha. The most dominant species are *Faidherbia albida* (28%), *Sclerocarya birrea* (28%), *Piliostigma reticulatum* (17%^) and *Hyphaene thebaica* (11%). In the RNA situation, sorghum, millet and cowpea yields increased by 12%, 7% and 3%, respectively compared to the situation without RNA. Later, they increase by 1% every year over the full life of the project (ELD, 2019: 37).

The net present value at 10% over a period of 20 years is positive (505,587 FCFA/ha = €772 /ha). This shows that FMNR is a financially viable practise for farmers and that their preference for the present is not a barrier to action (ELD, 2019: 40).

Also other studies of the costs and benefits of FMNR (Tahirou and Ibro, 2006) show that it makes economic and financial sense for farmers to invest in FMNR. Investments in small equipment are low (around €11). The labour time needed for tree and shrub maintenance is estimated at 2 days/year/ha This figure does not seem to take into account the time needed (individually and/or collectively) for the protection of the new tree capital against abusive cutting/theft of trees. But it is true that the time needed for tree protection and management is modest.

The hundreds of thousands of farmers in south-central Niger and elsewhere do not voluntarily invest in trees for their beauty, but they are motivated by the multiple benefits that trees produce in their farming systems.

5. Biophysical impacts

According to Bationo et al. (2018) agroforestry constitutes the foundation that supports the productive base of the land in arid and semi-arid zones. FMNR leads to the construction of new agroforestry parklands. This chapter first deals with the evolution of vegetation cover. What is the scale of regreening in the densely populated areas of south-central Niger and do farmers continue to maintain tree densities on their fields? The structure of woody vegetation is assessed, the impact of FMNR on biodiversity, the role of trees producing litter and this organic matter helping to improve the structure of the soil and increase its water retention capacity, and impacts on soil fertility.

5.1 Biodiversity

In the early 1980s, apart from some bird species, wildlife was rarely seen. Before the introduction of farmer-managed natural regeneration, there were no natural predators of pests, due to the lack of suitable habitats. Now, by applying the natural regeneration method, farmers are no longer dependent on artificial inputs for production, as pests can be controlled naturally (Abasse and Toudou, 2020). With the restoration of the vegetation cover and the rehabilitation of trees, wildlife has returned to the area. Predators such as birds and lizards and some insects have found shelter and breeding space in the trees. More birds are found on the project sites, which also contribute directly to crop yields by reducing pest populations (Abasse and Toudou, 2020). This outweighs a perceived disadvantage that the birds would eat the crops. Along with the increase in wildlife, rare plant species have also begun to make a comeback in the region.

Conventional reforestation campaigns have long focused on mono-specific plantations with exotic species (*Eucalyptus camaldulensis, Acacia holosericea, Acacia colei, Azadirachta indica, Prosopis juliflora,* etc.) that grow rapidly to compensate for the disappearance of many local species and the consequent specific erosion. The promotion of FMNR makes it possible, to a large extent, to compensate for the floristic erosion of several environments. With FMNR, there is a significant improvement in biodiversity based on local species that are adapted to the conditions of the environment and that have tended to disappear due to the strong harvesting pressures they have undergone.

Monospecific agroforestry fields or parklands (*Faidherbia albida* parklands) or those composed of 2 or 3 species have become sanctuaries of plant biodiversity. For example, in the village of Dan Saga and Aguié and El Guéza (Maradi region), there were few trees in terms of density and few species in terms of diversity in the 1980s, but today, the agroforestry parklands have at least thirty species, not counting the return of herbaceous species and micro-organisms. Currently, villagers are reintroducing species that disappeared in the 1970s and 1980s (Zarafi, 2002; Larwanou and Saadou, 2005). On RNA sites, tree density can be as high as 153 trees per hectare in Dan Saga, in contrast to non-RNA sites where the density does not exceed 40 trees/ha (Baggnian *et al.*, 2019; Rabiou *et al.*, 2020).

5.2 Demographic characteristics of woody plants

FMNR sites are characterised by greater heterogeneity in terms of distribution and spatial spread. In the FMNR fields, the trees have different sizes, i.e. there are young trees and mature individuals. In contrast, in fields without FMNR, trees tend to have large diameters. This dominance of large trees is only a consequence of the absence of FMNR. Sites without FMNR are often characterised by a high density of juveniles, which are systematically removed each year. In contrast, sites with FMNR are generally characterised by high densities. This density is a consequence not only of the practise of FMNR but also of other factors such as the supply of organic fertiliser, the fertiliser contract and the enrichment plantations. This heterogeneity may explain the more or less different perception of the interest of the population in practising FMNR. For some, the higher density of trees in the fields may be a factor in reducing yields through the shade created by the trees. For other farmers, the high density is a factor that increases yield through the maintenance of soil moisture for the benefit of crops and the dissemination of soil organic matter.

Table 4 below gives the average tree density on a number of FMNR sites. It is interesting to note that the number of trees in the North Sahel sites is higher than in the South Sahel and North Sudan, while the rainfall in the North Sahel is lower.

Table 4. Tree densities in some FMNR sites in Maradi and Zinder

Sites	Agroecological zones	Density (trees/ha)	Source
Guidan Ara Mijinyawa	north Sahel	107	Mamane, 2017
El Guïeza	north Sahel	109	Baggnian *et al.*, 2013
Dan Saga	north Sahel	151	Baggnian *et al..*, 2013
Zedrawa	south Sahel	79	Baggnian *et al.*, 2013
Oumba	north Sudanian	60	Sabiou, 2019
Sarkin Yamma	north Sudanian	63	Sabiou, 2019
Ara Sofoua	north Sudanian	65	Baggnian *et al.*, 2013

5.3 Litter production

Maintaining or increasing the amount of organic matter in the soil improves its fertility and allows for greater water storage. It is therefore important to see whether increasing the number of trees in agricultural production systems increases the production of litter = organic matter and in what quantities.

Especially in the densely populated areas of the Maradi and Zinder regions, a process of "greening" or "revegetation" through FMNR is taking place (Baggnian *et al.*, 2013). The latter contributes to the improvement of soil fertility and agricultural production (Larwanou *et al.*, 2006; Bationo *et al.*, 2018).

The FMNR plays this role through its contribution of litter that enriches the soil with bioelements contained in these organs, the largest component of which is leaves. Several studies have quantified the litter production of species present on FMNR sites and revealed that litter production varies according to the species, the size of the trees and shrubs, their density, the ecological conditions and the seasons of the year.

Zounon (2021) studied the litterfall production of the three main species in FMNR sites in the Maradi Region. These are *Piliostigma reticulatum, Guiera senegalensis* and *Combretum glutinosum*. Analysis of litter productivity shows that the most productive species are *Piliostigma reticulatum* and *Combretum glutinosum*. A plant of *Combretum glutinosum* produces up to 11.3±7.4 kg of foliage per year, whereas a plant of *Piliostigma reticulatum* can produce up to 9.4±5.7 kg of foliage per year. Given the high density of these species in the ecosystems of the Maradi region, they can produce an average of 169±53 and 158±36 kg of litter respectively for *Piliostigma reticulatum* and *Combretum glutinosum*.

The maximum average litter production is 14.2±10.5 kg/tree for *Combretum glutinosum* and 10.9±6.3 kg/tree for *Piliostigma reticulatum* on a crown area of 57 m2 each. *Guiera senegalensis* reached a maximum production of 2.1±1.4 kg/tree for a crown area of 28 m2. Zomboudre (2009) found that *Faidherbia albida* produced 7.8 kg tree per year of litter on an average canopy area of 194 m2.

The analysis of regeneration density in the RNA sites in the Maradi region shows that the species that stands out remarkably is *Guiera senegalensis*. The latter is a pioneer that has been the subject of several studies. These include the work of Issoufou *et al* (2013) and Douma *et al.* (2012). According to these authors, *Guiera senegalesis* is a semi-perennial Combretaceae, whose dominance has increased with agricultural pressure in the Sudano-Sahelian strip where it plays an important socio-economic and agroforestry role. The stumps and young shoots of *Guiera senegalensis* are the first to colonize the fields in the first year of fallow. *Guiera senegalensis* is the most represented species among the young plants. According to Douma *et al.* (2012), the clearing is done without stump removal and the reconstitution of the woody vegetation is done from the stumps and roots, which are a source of shoots and suckers. These authors add that it is the high reproductive capacity of Combretaceae (strong aptitude for vegetative propagation) that could be at the origin of their strong presence in all the FMNR zones of the Maradi region.

Analysis of the correlation between diameter class structures and leaf productivity showed that litter production is more important in the medium diameter class for *Combretum glutinosum* and Guiera *senegalensis*. While for *Piliostigma reticulatum* the highest litterfall production is obtained in the individual classes. For all three species, litterfall production is higher in the Sahelo-Sudanian zone than in other zones. This may be due to the physiology of the species, the collection periods and perhaps the edaphic characteristics of the area (Goma-Tchimbakala *et al.*, 2005).

Table 5 (page 34) shows that FMNR produces organic matter that helps maintain soil fertility. Of course, there are FMNR sites with much higher tree densities. Finally, it should be noted here that organic matter also boosts biological life in the soil. It attracts, for example, termites that dig galleries in the soil, which increases their water storage capacity, and the termites bring up fertilizing elements from the subsoil, making them available to the crop roots.

Table 5. Distribution of dominant species in the RNA sites and their biomass

Dominant species	Density (trees/ha)	Regeneration density (plants/ha)	Average biomass per plant (kg)	Biomass by species (kg/ha)
Piliostigma reticulatum	18.0 ± 9.4 b	31.3 ± 21.0 b	9.4 ± 5.7 b	169.2 ± 53.5 a
Combretum glutinosum	14.0 ± 5.2 a	153.3 ± 120.3 a	11.3 ± 7.4 a	158.2 ± 36.4 a
Guiera senegalensis	14.1 ± 5.5 a	589.8 ± 475.1 c	2.3 ± 1.2 c	32.2 ± 6.5 b
P-Value	0.026	<0.001 *	<0.001 *	<0.001 *

Figure 22. The litter produced by a parkland dominated by *Combretum glutinosum*. Photo: Chris Reij

5.4 Soil fertility

Farmers invest in trees mainly to maintain or improve the fertility of their soils and they are very aware of the impact of certain species on fertility, which is confirmed by many studies (Mansour *et al.*, 2013; Camara *et al.*, 2017; Dan Lamso *et al.* 2015a, 2015b; Zounon *et al.*, 2020; Traoré, 2012; Bodo *et al.*, 2019). The results showed that the practise of FMNR improves chemical fertilizer content, biological activity and soil structure. The work of Zounon (2021) revealed that soils under *Combretum glutinosum*, *Piliostigma reticulatum* and *Guiera senegalensis* dominating RNA sites in Maradi region have higher C (%), N (%), TP (ppm), K (meq/100g) and C/N contents than soils outside of the canopy. The higher carbon content should increase nutrient and moisture use efficiencies. The same observations were made by Mansour *et al* (2013) on *Acacia senegal* and Camara *et al* (2017) on *Guiera senegalensis*. Decomposition followed by mineralization of the biomass of these species is generally accompanied by nutrient enrichment for the crops. These results are in agreement with those of Traoré (2012) who reports that organic matter and nitrogen levels are higher in soils under tree canopies than outside. Similar results are also obtained by Mansour *et al.* (2013) and Camara *et al.* (2017) who report that soils under tree canopies are more fertile than soils outside the canopies for *Acacia senegal* and *Guiera senegalensis*, respectively.

The work of Dan Lamso *et al* (2015) showed that *Guiera senegalensis* bushes significantly improve soil fertility and physical properties of soils located near the bushes. Also, recent studies by Boureima *et al* (2019) have shown that FMNR favours the installation and development of mycorrhizal symbiotic activity in cultivated fields. The study found that mycorrhization frequency was higher in FMNR fields older than 10 years and lower in younger fields. Also, the results showed that the roots of *Combretum glutinosum* are strongly associated with arbuscular mycorrhizal fungi. Because of its functions within the system, the tree acts as a reservoir for propagules that can associate with crop species and thus improve their yield.

Work by Zounon (2021) has shown that the presence of animals under the tree canopy also contributes to nutrient enrichment.. Animals come to graze directly under the trees or to rest in the shade and leave their faeces. These results are in agreement with the work of Bodo *et al*. (2019) who found that the presence of trees creates positive heterogeneity within agricultural plots in the Sahelian zone, favourable to crop production.

The analysis of the impacts of three dominant FMNR species in the Maradi region on soil fertility shows that the influence of these species differs depending on whether one is in the less watered northern zone (Sahelian) or the more watered southern zone (northern Sudanian). In fact, the content of certain elements increases in the Sahelian zone. These are C, N and K in the under-tree zone and N in the non-tree zone of *Combretum glutinosum*. For *Guiera senegalensis*, this increase along the gradient is observed for N and P content in the under-top soil. For *Piliostigma reticulatum*, it is only K that increases from the Sahelian to the north Sudanian zone. This variation may be due to the variation in environmental and climatic conditions, but also to agricultural practises which may vary from one zone to another. The Sahelian and Sahelo-Sudanian zones are the areas par excellence for tigernut cultivation, which is traditionally exploited by disturbing the surface layer of the soil, exposing it to erosion.

Table 6 (page 36) shows soil carbon (C%) and potassium (K (meq/100g)) levels higher under tree crowns than outside the crown. This suggests that increasing tree density is always followed by an improvement in soil fertility. A study by Dan Lamso *et al* (2022) showed that FMNR is an effective fertility management practise for tropical ferruginous soils grown in Niger. Indeed, the presence of trees significantly improves the chemical fertility of these soils.

Table 6. Chemical soil fertility elements between areas under and outside *Combretum glutinosum*, *Guiera senegalensis* and *Piliostigma reticulatum* stands in the Sahelo-Sudanian zone

	Under tree canopy	Outside tree canopy	Probability
	Combretum glutinosum		
C (%)	0,4±0,018a	0,3±0, 11a	0,091
N (%)	0,04±0,008a	0,02±0,01a	0,078
PT (ppm)	16,8±2,7a	20,4±5,3a	0,217
K (méq/ 100g)	0,098±0,03a	0, 102±0,016a	0,802
C/N	10,29±1,6a	10,684±1,042a	0,675
	Guiera senegalensis		
C (%)	0,43±0,02a	0,318±0,075b	0,009
N (%)	0,03±0,006a	0,034±0,011a	0,733
PT (ppm)	18,02±4,2a	20,42±3,29a	0,347
K (méq/ 100g)	0, 1±0,011a	0,096±0,017a	0,521
C/N	12,4±0,65a	10,024±1,511b	0,012
	Piliostigma reticulatum		
C (%)	0,444±0,082a	0,248±0,062b	0,003
N (%)	0,038±0,008a	0,026±0,006b	0,028
PT (ppm)	25,23±6,58a	20,42±5,38a	0,242
K (méq/ 100g)	0, 142±0,033a	0, 112±0,018a	0, 110
C/N	11, 198±0,758a	9,916±1,008a	0,053

Organic matter contents are 26, 3.8 and 4.2 times higher respectively under the canopy of *Piliostigma reticulatum*, *Combretum glutinosum* and *Scleocarya birrea* than outside the canopy of these species. In addition, the assimilable phosphorus content, which is often very low in the tropical ferruginous soils cultivated in Niger, is 2.5, 1.2 and 2.1 times higher in the under-top soil than in the out-of-top soil of these three species respectively. Thus, FMNR improves the chemical fertility of cultivated tropical ferruginous soils through the supply of organic matter and mineral elements through litter and the trapping of wind-borne particles.

6. FMNR and climate change adaptation

Agriculture in Niger (and elsewhere in Africa) must adapt to more erratic and extreme rainfall and higher temperatures. How can the negative impacts of climate change be reduced and agricultural yields maintained and even improved? To succeed, it is important to create more complex production systems that integrate agriculture, livestock and forestry. Interestingly, this is exactly what farmers in south-central Niger have been doing on a large scale since the mid-1980s. In other regions (e.g. Tahoua) the focus has been on introducing water harvesting techniques to restore severely degraded land. As already seen in section 3, FMNR has increased agricultural yields and improved food security for the hundreds of thousands of families who have invested in it.

In this review, two levels of adaptation will be addressed: (i) adaptation within FMNR-based forest species; and (ii) community adaptation following the adoption of FMNR. This chapter will also address important themes such as FMNR and carbon sequestration in biomass and soil organic carbon. If farmers in south-central Niger are sequestering large amounts of carbon, they are doing the international community a favour in the fight against climate change. The last theme addressed in this section concerns the question of whether regreening in Niger is the result of increased rainfall or a change in human management of vegetation.

6.1 FMNR and adaptation of woody species

In the Maradi and Zinder regions, woody stands in FMNR fields are most often dominated by *Combretum glutinosum, Combretum micranthum, Piliostigma reticulatum, Guiera senegalensis, Faidherbia albida* and *Prosopis africana* (Baggnian *et al.*, 2014; Moussa *et al.*, 2015; Mamane, 2017; Maâzou, 2019). According to these authors, the specific contribution of each species is highly variable, up to more than 50% of the total tree population. Table 7 (page 38) presents the specific contribution of the dominant species of the FMNR according to the agroecological zones. In this table, only species with a contribution of 10% or more are included to make the table more synthetic. There are about ten species in the three agroecological zones. The varied composition of species reinforces the adaptation of agroforestry parklands since each species has its own intrinsic value in responding to climate variability (Moussa *et al.*, 2021). While adaptation is a dynamic issue, due to the lack of monitoring of permanent plots, Table 7 gives an indication of species status based on available data.

6.2 Adaptation-based regeneration

Regeneration is an important parameter for the adaptation of forest ecosystems to climate change and anthropogenic pressures. Under the combined action of anthropic and climatic pressure, some species, for example *Parkia biglobosa* (locust bean) and *Hyphaene thebaica*, are disappearing due to their inability to withstand the various stresses. The population of the village of Dan Mairo (Maradi Region) has identified 22 species that have disappeared in their area (Moussa *et al.*, 2016). The capacity of woody species to resist under stressful conditions could be a bulwark. Adaptation can

Table 7. Specific contribution of some dominant FMNR species according to agroecological zones

Dominant species	Specific contribution (%)	Site	Agroecological zone	Source
Acacia tortilis	22	Adouna	Nord Sahel	Mamane, 2017
Annona senegalensis	15	Ara Sofoua	Sud Sahel	Baggnian *et al.* 2013
	23	Zedrawa	Sud Sahel	Baggnian *et al.* 2013
	22	Daŕe	Sud Sahel	Baggnian *et al.* 2013
Balanites aegyptiaca	68	Mai Guero	Nord Soudan	Moussa *et al.*, 2020
	30	Adouna	Nord Sahel	Mamane, 2017
Bauhinia rufescens	21	Adouna	Nord Sahel	Mamane, 2017
Combretum glutinosum	12	Sarkin Yamma	Nord Soudan	Sabiou, 2019
	10	Dan Saga	Nord Sahel	Baggnian *et al.* 2013
Faidherbia albida	56	Dan Mairo	Nord Sahel	Moussa et al. 2015
	12	Guidan Sori	Sud Sahel	Maazou, 2019
	24	Adouna	Nord Sahel	Mamane, 2017
	46	Droum	Sud Sahel	Mamane, 2017
	22	Ara Sofoua	Sud Sahel	Baggnian *et al.* 2013
	28	Zedrawa	Sud Sahel	Baggnian *et al.* 2013
	22	Daŕe	Sud Sahel	Baggnian *et al.* 2013
	30	El Guïeza	Sud Sahel	Baggnian *et al.* 2013
	11	Dan Saga	Nord Sahel	Baggnian *et al.* 2013
Guiera senegalensis	17	Sarkin Yamma	Nord Soudan	Sabiou, 2019
	57	Guidan ara Mijinyawa	Nord Sahel	Mamane, 2017
Hyphaene thebaica	14	Droum	Sud Sahel	Mamane, 2017
Piliostigma reticulatum	54	Sarkin Yamma	Nord Soudan	Sabiou, 2019
	27	Guidan ara Mijinyawa	Nord Sahel	Mamane, 2017
	10	Droum	Sud Sahel	Mamane, 2017
	29	Guidan Sori	Sud Sahel	Maazou, 2019
	16	Ara Sofoua	Sud Sahel	Baggnian *et al.* 2013
	18	El Guïeza	Sud Sahel	Baggnian *et al.*, 2013
Prosopis africana	52	Sarkin Yamma	Sud Sahel	Moussa *et al.* 2015
	12	Zedrawa	Sud Sahel	Baggnian *et al.*, 2013
	12	El Guïeza	Sud Sahel	Baggnian *et al.*, 2013
Ziziphus mauritiana	54	Birnin Lallé	Nord Sahel	Moussa *et al.*, 2020

also be assisted by tree planting or any other young shoot maintenance actions. FMNR is a practise that promotes the multiplication of active (seed) and especially passive (vegetative) regeneration of trees in the field. In areas where the practise of FMNR is highly developed, all species have the capacity to regenerate to varying degrees. It is important to point out thyat FMNR species like *Faidherbia albida* also propagate by highly nutritious pods that are readily consumed by livestock that, in turn, scarify and spread the seed.

Moussa *et al.* (2016) classified woody species according to their age abundance measured using the importance value index (IVI), and juveniles into resilience types in agroforestry parklands.

(i) Species with high IVI and strong regeneration (*Prosopis africana, Piliostigma reticulatum, Faidherbia albida* and *Combretum glutinosum*). These species are marked by their considerable number of individuals, which allows them to spread by seed and a high rate of regeneration. They are the most resilient because they ensure succession with young shoots and dissemination with seeds.

(ii) Species with low IVI and high regeneration (*Guiera senegalensis, Ziziphus. mauritiana, Bauhinia rufescens, Maerua crassifolia, Balanites aegyptiaca, Acacia senegal, Albizia chevalieri* and *Hyphaene thebaica*). This category of species is less resilient than the first. Mature trees are poorly represented, while regeneration is high in parklands. This is due to the fact that these species are either regularly cut or have few large trees.

(iii) Species with very low IVI and no regeneration (*Tamarindus indica, Acacia nilotica, Adansonia digitata, Boscia salicifolia, Sterculia setigera* and *Dyospiros mespiliformis*). These are very rare parkland species due to their ecological and practical management requirements.

(iv) Species with regeneration but without mature trees (*Securidaca longepedunculata, Entada africana, Cassia singueana, Terminalia avicennioides, Feretia apodanthera, Combretum micranthum, Commiphora africana, Ficus platyphylla* and *Calotropis procera*). These same observations were made by Baggnian *et* al. (2014). This would be related to the management style of the producers and especially to the requirement of the species. Cutting tolerance is also a fundamental factor in species rejection (Baggnian *et al.*, 2013).

6.3 FMNR and community resilience

By investing in trees on their fields, farmers in the Zinder and Maradi regions of Niger have created more complex production systems (integration of agriculture, livestock and forestry) that are more productive (impacts on crop yields and wood and non-wood products) and more sustainable (increases in impacts over time), that contribute to a reduction in rural poverty (chapter ....), and that reduce vulnerability to drought years and increase biodiversity.

FMNR helps communities to adapt to climate change by (i) improving agricultural production even in drought years, (ii) increasing incomes, and (iii) strengthening social capital.

Improved agricultural production also in drought years

Farmers report a big change in food availability, especially for millet and sorghum. An increase in seed yields has been observed. This translates into better food security at the family level even in years

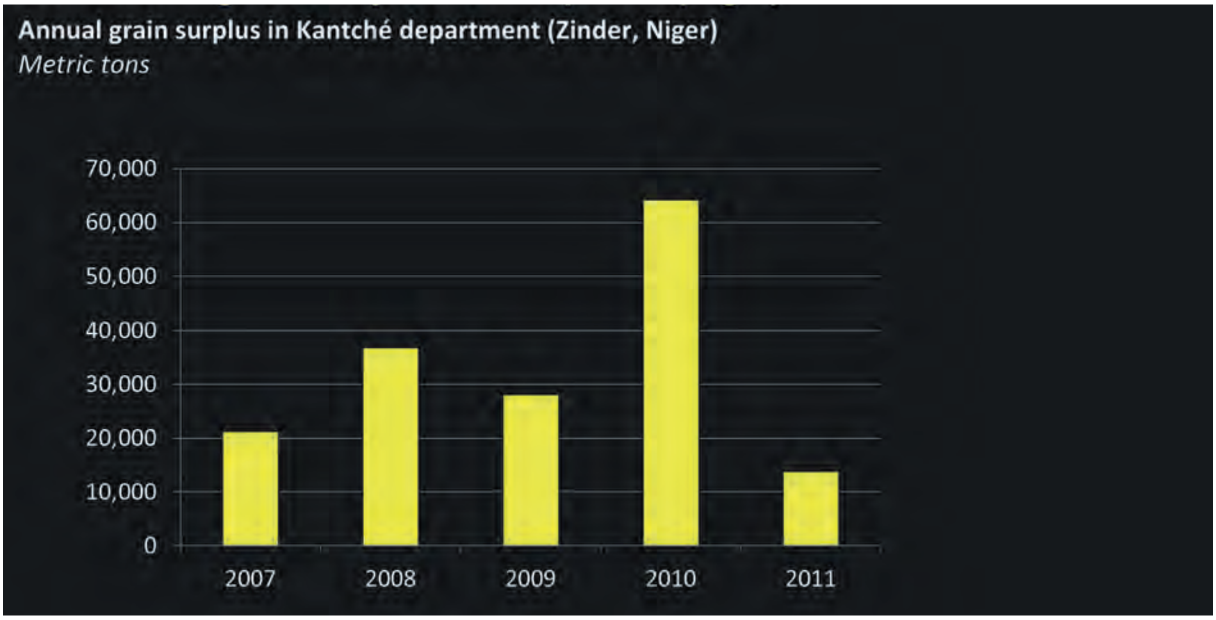


Figure 23. Evolution of cereal surpluses in the department of Kantché characterised by a dense population and high tree densities (Yamba and Sambo, 2012)

of poor rainfall. As mentioned before, Yamba and Sambo (2012) conducted a study in two densely populated departments (Kantché and Mirriah) with high tree densities in southern Zinder to see the impacts of the 2011 drought on agricultural production. They used data from the USAID Famine Early Warning Systems Project, which showed that Kantché district produced a surplus of seeds in 2011 of almost 13,000 tonnes. From 2007 to 2010 the surplus was even higher. Having produced a surplus does not of course guarantee that there were no families who suffered in 2011-2012, but the situation would have been worse without a surplus at the department level. Surveys by Yamba and Sambo (2012) showed that 58% of heads of household (men) said that they invest in FMNR to improve soil fertility, which has a positive impact on agricultural yields.

Increased income

Food security depends not only on agricultural production, but also on the sale of wood and non-wood forest products. In the Aguié area, the sale of FMNR products generated an annual income of 19,793,291 FCFA (€30,172), or 199,932 (€305) ± 33,624 FCFA (€51) per household, which reduces rural poverty and increases the level of household food coverage, as this income allows households to buy food at the market when needed. A study by Baggnian (2010), claims that the action of trees increases the duration of agricultural production stock from 5 to 7 months on average, which contributes significantly to food stability.

Several studies (Sitou *et al.*, 2018; Ado *et al.*, 2019) have reported that FMNR could be a strategy to combat food insecurity through the sale and marketing of wood products. A study carried out by the Regional Directorate of the Environment of Maradi, reported by Yamba (2017), maintains that women who practise FMNR made the following statements: "I manage to fully satisfy the needs of my family and I prefer to work in this sector than to work even at the level of the civil service". Another also considers that "the sector is very promising in our areas, it protects us from food insecurity and poverty". Sitou et al. (2018) also pointed out that ceremonies take up 42% of income, means of production 23% (maintenance of houses, fields and means of transport) and human food and clothing consume 26%.

Strengthening social capital

The management of FMNR is often accompanied by better consultation and organisation within the villages in order to manage the new tree capital well. The village of Dan Saga (Maradi Region) is often cited as an example (Pye-Smith, 2013). This village has a committee for the protection and management of trees. This committee with representatives of men, women and sedentary herders monitors the application of the management rules adopted by the village, but also the proper functioning of the rural timber market. At the same time, this committee has taken the initiative to create a seed bank of trees and shrubs in their area and the committee has created a cereal bank to cover deficit years.

6.4 Mitigation of extreme weather events

FMNR has a major role to play in mitigating environmental risks. It is recognized as an effective approach for a diversity of environmental services and for minimising the risks associated with climate

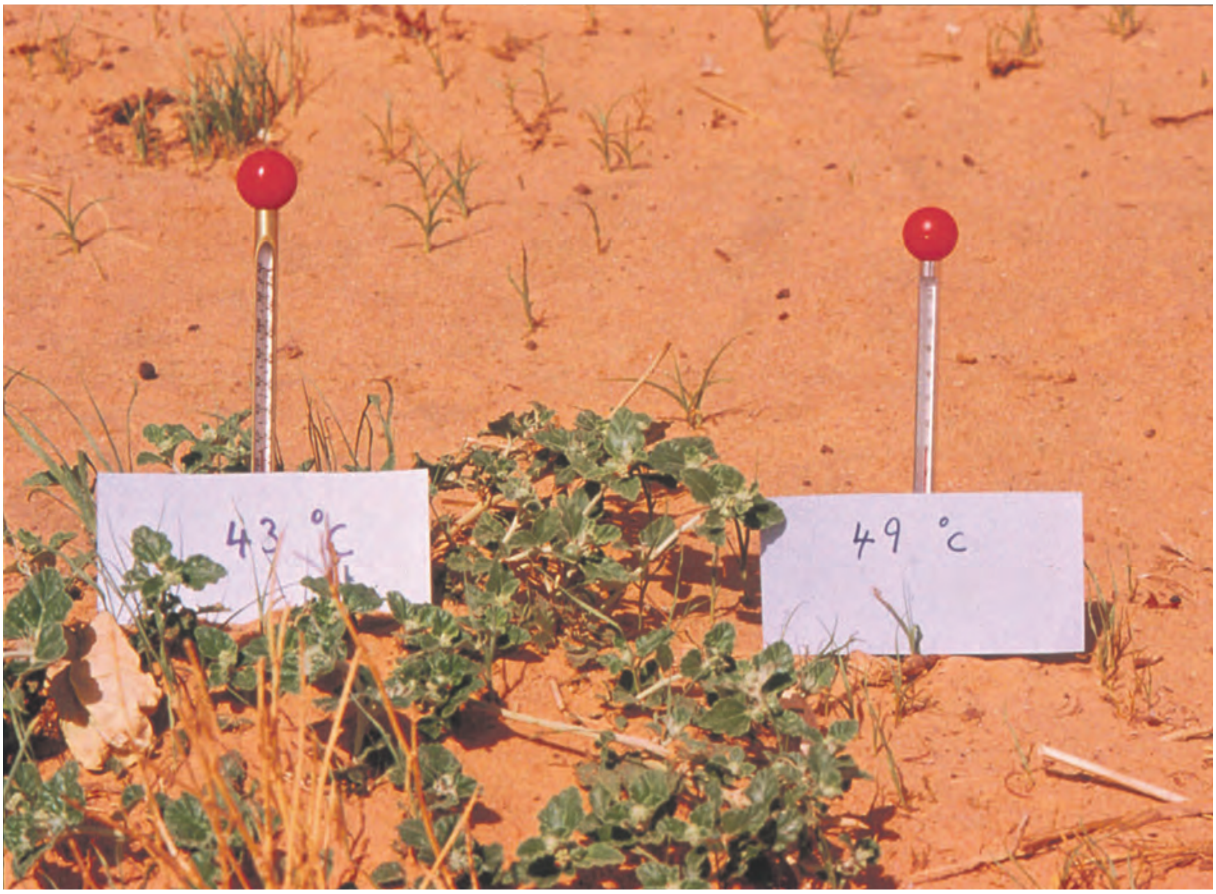


Figure 24. Vegetation reduces soil temperature. Photo: Tony Rinaudo

variability and change to production and populations. Indeed, FMNR has a strong potential to diversify and increase the density of trees in the landscape (Larwanou *et al.* 2006; Baggnian *et al.*, 2014). Increasing trees in the landscape substantially influences rainfall interception, evapotranspiration, water infiltration and groundwater recharge. It limits extreme temperature variations, thus contributing to the mitigation of heat waves.

Figure 24 shows that even a few leaves help to reduce the soil surface temperature by 6°C. Under tree crowns this will be even more. Everyone knows this, but there is a lack of figures on the impacts of regreening in south-central Niger on, for example, rainfall and microclimate. Many farmers are convinced of "more trees, more rain" and studies seem to confirm this

6.5 FMNR and carbon sequestration

Farmers in south-central Niger have over the years added at least 200 million trees and shrubs to their production systems. These trees sequester significant amounts of carbon, but very few studies in Niger have attempted to calculate how much carbon is sequestered by the new agroforestry parklands. Reij and Winterbottom (2015) estimate that these agroforestry parklands in Niger sequester between 1.6 and 10 t/ha in their biomass. The amount depends of course on the species, their age and the density of the trees. The quantities sequestered in their root systems could be equal to the quantities sequestered in the biomass. If trees on one hectare sequester on average 6 tons of carbon in their above-ground part, this already amounts to 30 million tons (Reij and Garrity, 2016). According to Tappan (personal communication) the old *Faidherbia albida* parkland in the Senegalese groundnut basin sequesters up to 20 t/ha in the denser stands.

Carbon sequestration is defined as the process of removing carbon from the atmosphere and depositing it in a reservoir. It involves the transfer of atmospheric C, in particular CO2, and its safe storage in long-lived pools. Five carbon pools have been defined in a forest ecosystem. These are carbon from the above-ground part of trees, roots, soil, litter and dead wood. In this review, we will address vegetation carbon and to a large extent soil carbon despite the limitations of the available data (Moussa, 2016; Moussa and Larwanou, 2018). In agroforestry parklands, the carbon sequestered is variable depending on the species and their environment (Weber *et al.*, 2017; Moussa and Larwanaou, 2018). In the agroecosystems of the Maradi Region, under Prosopis africana parklands in the southern Sahel, with a density of 33 trees/ha (Moussa *et al.* 2015), this species sequestered 5110 kg/ha. Similarly for F. albida which sequestered 4220 kg/ha with a density of 17 trees/ha in an agroforestry parkland in the northern Sahel (Moussa *et al.*, 2015; Moussa and Larwanou, 2018). Table 8 presents results of studies on aerial carbon stocks of some agroforestry species. The analysis of this table shows a carbon sequestration capacity linked to the species and tree density. However, by promoting the density and diversity of trees in fields, FMNR contributes to carbon sequestration and the cost of mitigating the effects of climate change. However, below ground carbon stocks are not assessed in this study.

Knowledge of annual tree growth is necessary for any estimate of forest carbon. As with carbon stock, knowledge of annual increment of FMNR species is limited. The few existing data are related to a few Combretaceae and species that are often dominant in the parklands. Analysis of the following table 16 shows variation in annual increment and carbon accumulation. The growth data presented in this table are standardised data i.e. generated after extraction of non-climatic growth. This is an approach used in dendrochronology to look for the level of correlation between tree cambial growth and rainfall data (Moussa *et al.*, 2021). Saidou (2021) showed that landscapes revegetated by sustainable land management actions have a mitigating effect on climate change and variability. The focus was on the woody component to highlight the potential for landscape carbon sequestration in both Dan Saga and Tabofatt sites. This potential is significantly higher in the Dan Saga landscape (6040 tCO2/ha) than in the Tabofatt case (4590 tCO2/ha). In both cases, the uncertainty of the results is below the threshold value of 10%.

Table 8. Carbon stocks in the aboveground part of trees in Faidherbia albida, Prosopis africana and Balanites aegyptiaca parklands

Agroforestry systems	Localities	Diameter (cm)	Density (trees/ ha)	Carbon (kg.ha)	Source
F. *albida parkland*	Dan Mairo	5.73-65.92	17	3400	Moussa and Larwanou, 2018
P. *africana parkland*	Sarkin Yamma	5.73-44.58	33	5085	Moussa and Larwanou, 2018
B. *aegyptiaca parkland*	Torodi	-	45	6850	Adamou *et al.* 2020
B. *aegyptiaca parkland*	Sansani Haoussa	-	75	14660	Adamou *et al* 2020
B. *aegyptiaca parkland*	Tamou	-	56	6710	Adamou *et al.* 2020

Moussa and Larwanou's (2018) figures are based on densities of 20 trees/hectare and their calculation of sequestered carbon is based on measuring carbon in the trunk, branches and leaves of trees.

Table 9. Annual tree diameter growth and carbon accumulation in the above-ground part of some FMNR species

Species	Annual diameter growth (mm)	Carbon concentration	Units	Source
Combretum glutinosum	3,3	286	kg/m3	Weber *et al.*, 2017
Combretum micranthum	2,7	321	kg/m3	Weber *et al.*, 2017
Combretum nigricans	3,2	307	kg/m3	Weber *et al.* 2017
Guiera senegalensis	3,2	294	kg/m3	Weber *et al.*, 2017
Piliostigma reticulatum	3	238	kg/m3	Weber *et al.*, 2017
Prosopis africana	2,01	7,84	kg/tree/yr	Moussa *et al.*, 2020
Faidherbia albida	2,1	10,71	kg/tree/yr	Moussa *et al.*, 2020

Table 10. Some indications of soil organic carbon levels under the canopy of FMNR woody species

Agroforestry systems	Localities	Mean tree diameter(cm)	Soil depth under tree canopy (cm)	Organic carbon (%)	Source
B. aegyptiaca	Kourtché	9,46	0 - 20	0, 117	Boubacar *et al.*, 2019
B. aegyptiaca	Kourtché	9,46	20 - 40	0, 111	Boubacar *et al.*, 2019
A. senegalensis	Korto	24,34	0- 30	0,09	Diallo *et al.*, 2021
B. aegyptiaca	Korto	116,67	0- 30	0, 18	Diallo *et al.*, 2021
G. senegalensis	Korto	3,97	0- 30	0, 11	Diallo *et al.*, 2021
P. reticulatum	Korto	22,34	0- 30	0, 12	Diallo *et al.*, 2021
F. albida	N'Dounga	146,67	0 - 15	0,273	Kho *et al.*,2001
F. albida	N'Dounga	146,67	15 - 40	0, 146	Kho *et al.*,2001
F. albida	N'Dounga	146,67	40 - 90	0, 104	Kho *et al.*,2001

6.6 Soil organic carbon

Farmers are making efforts to maintain and improve the fertility of the soil in their fields. FMNR and many other practises contribute to this. One of the benefits of FMNR is the random distribution of carbon in the fields. Soil carbon is a by-product of the inevitable need to improve crop yields globally while reducing the rate of enrichment of atmospheric CO2 concentration (Lal, 2004). However, in Niger, very few studies are devoted to the quantification and dynamics of soil organic carbon in agroforestry parklands (Reij and Garrity, 2016). The few results that have been found focus on soil carbon levels under the influence of tree crowns. The carbon content varies from 0.11% to 0.27% (Table 10). It can be seen that the carbon content is highest under the tree crowns of Faidherbia albida. In a study by Bayala et al. (2020) in the Sahel including Niger, the carbon rate under FMNR is highest in the surface layer of the soil under FMNR trees. In a meta-analysis, Bayala *et al.* (2018) found that agroforestry practises, including alley cropping, improved fallow, mulching and parklands, increase CO2 compared to plots without trees used as controls. Practises that increase CO2 help to reintroduce ecological functions into production systems because of the various supporting ecosystem services associated with trees.

7. Forest policy changes promoting FMNR

After analysing the socioeconomic and biophysical impacts of FMNR, this chapter looks at the policy context that has hindered or stimulated the adoption and diffusion of FMNR in Niger. The emergence of FMNR was facilitated by a policy that started in 1984 when the government and its partners decided to put more responsibility for natural resource management in the hands of the population. Over the years there have been changes in forest policy and legislation in Niger, which have been influenced by the practise of FMNR. This shows us that practise precedes policy. Policy and legislative changes are rooted in achievements on the ground.

7.1 Governance dynamics and tree management

Before 1985, all trees belonged to the state. This was a legacy of the colonial period and was reflected in the country's 1974 Forestry Code. But since the late 1980s, farmers began to perceive that they had a right to the trees on their own farms. This change was catalysed by a national debate held in Maradi in 1984 on how to combat desertification. This perception led to increased participation of local communities in the management of their natural resources. De facto ownership of trees did not, however, mean that farmers could freely manage or cut trees on their farms as they wished. They still needed permission from the forestry department to harvest 'their' trees, or even to prune them. It was not until 2004 that the Forestry Code established the rights of communities over their own trees, which they could manage and exploit with the approval and technical support of the forestry service.

In order to meet the challenges posed by the strong demographic growth and the excessive dependence of rural populations on natural resources, several programmes and projects to support rural development and natural resource management have been implemented in Niger. The interventions have enabled the capitalisation of important experiences and achievements in the protection and restoration of the environment in general and sustainable land management in particular. However, unfavourable legislation on land ownership and tree users' rights has been cited as an obstacle to the effective implementation of FMNR (Rinaudo, 2011). Given the efforts of local people to restore their ecosystems, several studies have identified the need for new legal provisions to enable sustained management of these resources. A legal provision that would allow for the real and effective appropriation of trees outside the forest to the person protecting it was an inescapable solution to ensure the sustainability of these woody resources (Adamou, 2016).

7.2 Evolution of forestry policy

The evolution of national forestry policy can be summarised in three major sequences:

The pre-colonial period was marked by community management under the aegis of land chiefs and bushmasters and more generally under the authority of traditional chiefs. There was a balance between pressure (which was low) and the amount of forest resource available.

The colonial period was also marked by the adoption of the decree of 4 July 1935 establishing the forestry regime in West Africa. The colonial authority then adopted a policy of conservation of forest resources (classification of forests, reserves and parklands; management of exploitation; issuance of cutting permits) and the establishment of a forestry administration responsible for forest policing. The conservation policy promoted during this period resulted in the classification of about 600,000 ha of forest as natural parklands, protected areas and classified forests.

The post-colonial period saw several major developments in the management of forest resources:

– From 1960 to 1980, forest management was exclusively reserved for the state, either through the sale of production permits or through the state's control of the forest.

– From the 1980s onwards, in view of the mixed results of the authoritarian and protectionist approach, reflections were carried out with a view to a more global and integrated management of forest resources by directing it towards the main beneficiaries (1984 of the national debate on the fight against desertification; the "cooperative forestry" approach, then the "rural wood markets" approach).

During this period, large-scale reforestation efforts continued, but without being able to respond adequately to the challenge of forest cover loss, increasingly confronted with the effects of climate change and demographic pressures. Thus, in addition to the classic planting operations, other technologies such as Assisted Natural Regeneration (FMNR) appeared in farmers' practises, first in the regions of Zinder, Maradi and Dosso, and progressively in other regions such as Tahoua. At the same time, donors (e.g. IFAD, World Bank, GEF) also started to recognise and support FMNR. The will to empower populations and diversify techniques is clearly reflected in the different policy or programming documents adopted by the State in recent years, which constitute reference frameworks for the implementation of forest resource management actions.

The National Policy on Environment and Sustainable Development was adopted by decree N°2016-522/PRN/ME/DD of 28 September 2016 and has as its vision "To promote a sustained management of natural resources while developing the resilience of populations to natural hazards so as to ensure sustainable food and nutritional security for present and future generations".

Law 2004-040 of 8 June 2004 on the forest regime in Niger

One of the highlights of this law is the inclusion of agroforestry park resources in the forest heritage, which provides the legal basis for securing and managing this important category of forest resources, which is developing in the country. For the first time, Niger's forestry law recognises the right of local authorities to appropriate and take ownership of their own forest heritage, which they can manage freely, with the support of the forestry administration. The old idea that the trees in the farmers' fields are not their property is over.

An institutional response has been found which consists in changing the status of the tree. Indeed, changes in the Nigerien forestry code in 2004 have created a more favourable environment for the practise of FMNR. Botoni *et al.* (2010) state that once farmers became aware that they had the right to manage their trees, prune, trim and even thin them without being fined by the forestry services, this encouraged them to protect the regrowth of trees in their fields.

In this context it is also worth mentioning the efforts of CILSS and the Club du Sahel, which since the late 1980s have made efforts to promote decentralisation of natural resource management in the Sahel. A key event was the organisation of a regional meeting in Segou (Mali) in 1989 on village land management in the Sahel. This was the first conference in the Sahel that brought together policy makers, donor representatives and representatives of farmers' organisations. An important book served as a basis for the conference: "Le Sahel en Lutte contre la Désertification: lecons d'expériences" (Rochette, 1989).

Mention should be made of the efforts of IFAD-funded projects in the Maradi region to create and empower village organisations for the protection and management of trees in their territories. There has been the setting up of Management Committees for Regeneration and Silvopastoral Spaces (CG/RN/ESP), which have a role in raising awareness of the practise of FMNR and securing the important woody potential created by FMNR: monitoring regenerated trees so that they are not cut down abusively by fraudsters. The roles of these committees have enabled rapid dissemination of the technique and significant regeneration of trees in the fields. Promoting FMNR is not only about promoting a simple and reproducible technique (tree capital), but also requires the development of village organisations (social capital).

Presidential Decree of 30 July 2020

The adoption of Decree N°2020- 602/PRN/MESUDD of 30 July 2020 regulating the practise of assisted natural regeneration in Niger (FMNR) was a major step forward in the governance of natural resources. The latter has been the subject of advocacy by civil society actors since a national workshop

Figure 25. Meeting of the Dan Saga village regeneration management committee. Photo: Chris Reij

on agroforestry in 2013 and especially since 2018-2019. The baseline study conducted on "Laws and policies on FMNR and sustainable land use practises" served as the basis for recommendations to the State of Niger. This decree marks the official recognition by the State of Niger of the importance of this practise, the need to generalise it, ensure its sustainability and ensure that practitioners benefit from their efforts. The law stipulates that the planted or regenerated trees now belong to the producer. This regulation fills a long-standing gap in the legal framework. Producers need not fear that others will cut down and take their trees. It gives a field owner the "exclusive right to exploit the green wood from the agroforestry on his field". In addition, landowners are now encouraged to legally establish "village committees to monitor the trees" and are fully supported in this by the technical extension services of the Ministry of Environment who are in charge of monitoring national progress of FMNR.

7.3 Interventions to scale up FMNR

In view of the magnitude of land degradation affecting crop lands and all ecosystems, the government of Niger is committed to investing more in restoration activities. For this reason, the country has expressed its adherence to the African Forest Landscape Restoration initiative (AFR100) which aims to restore 100 million ha by 2030. This endorsement is seen with the signing of a letter of commitment to restore 3.2 million ha of degraded land over the period 2015-2029. To achieve this, Niger plans to further promote agroforestry, including assisted natural regeneration. Thus, in the investment plan of the Strategic Framework for Sustainable Management, it is planned to implement assisted natural regeneration on 1,100,000 ha over 2015-2029. In the framework of the investment plan of the "3N" Initiative, the objective was to restore 350,000 ha using assisted natural regeneration in 2016-2021, and according to reports, 495,000 ha was achieved.

The first IFAD-funded FMNR promotion project covered 65 villages in the department of Aguié from 2006 to 2010, with an estimated area of nearly 13,000 ha of cultivated land under regeneration. Also, 65 monitoring committees were set up and trained in the 65 villages (PPILDA, 2013). There was a strong potential for replication of the success of PPILDA activities. The success of the FMNR in the PPILDA comes in particular from a strong involvement of the beneficiaries thanks to participatory approaches and self-targeting, as well as the accessibility of the activities for the poorest: actions requiring investments within the reach of all, and whose interest quickly becomes obvious (PPILDA, 2013).

Since 2013, the project successfully scaled up the extension of FMNR thanks to the signing of six agreements with specialized NGOs, which in association with a Groupement d’Appui-Conseil Agricole Paysan (GACAP) in Dan Saga, have continued to promote FMNR on 82,000 ha, benefiting 41,000 smallholder farmers, 53% of whom are men, 21% women and 23% young men and women (PASADEM, 2015). By October 2020, the Family Farming Development Programme (ProDAF), which operates in the regions of Maradi, Zinder, Tahoua and Diffa, had restored 188,000 ha using assisted natural regeneration.

There are other projects that have promoted FMNR, but the investments made by these projects over a 30-40 year period from the mid-1980s to 2021 are much less than €200 million. The scale of FMNR in south-central Niger is 5 million hectares. According to Tappan (personal communication), for the whole of Niger the area under FMNR is about 6 million hectares, which is about 50% of the cultivated area.

8. Conclusions and recommendations

Farmers in south-central Niger have intensified their agricultural production systems by increasing the number of trees and shrubs on their fields. They have not done this by planting, but by protecting and managing the natural regeneration of trees and shrubs. Since the mid-1980s, hundreds of thousands of smallholder farmers in the densely populated parts of south-central Niger have started to practise Farmer-Managed Natural Regeneration (FMNR) and by doing so they have created new agroforestry landscapes at scale

The transformation of the landscape on millions of hectares in this region of Niger is the result of a combination of factors. These stemmed from a crisis in agriculture (low and decreasing soil fertility; low crop yields) and the environment, putting farmers into a difficult position, seeing that they had to do something differently. They began to perceive FMNR as a simple and effective technique that does not require them to invest any money in the purchase of inputs. A modest investment in labour produces multiple benefits fairly rapidly (e.g. increase in crop yields, more fodder for livestock and more fuelwood). Several projects promoted FMNR, and that also created and strengthened village organizations to manage this new tree capital. In addition, government policy has put responsibility for natural resource management increasingly in the hands of farmers, and recognizes that farmers have an exclusive right to the trees in their fields.

The hundreds of thousands smallholder farmers investing in FMNR have not been paid by projects to do so. They voluntarily decided to invest in the protection and management of woody species growing on their farmland. They were driven by the multiple benefits produced by FMNR.

An increase in rainfall in some years since the 1990s has had a favourable impact on the regeneration of the vegetation cover, but this alone cannot explain the massive regreening; profound changes in tree management have been the most decisive factor. Faced with the agricultural crisis of the 1970s and 1980s, the population had no choice: intensify agriculture or abandon their land. The impossibility of feeding their families and the serious shortage of fuelwood led farmers to increase the number of trees on their fields. It led to reduced wind erosion and avoiding the need for resowing crops.

Farmers have increased on-farm tree numbers to improve soil fertility, which is why they want high-densities of *Faidherbia albida*, a nitrogen-fixing species. Also other local and common species with a perceived impact on soil fertility (e.g. *Piliostigma reticulatum*) are protected and managed. Many woody species also produce fodder for livestock. The increase in on-farm tree numbers has led to a stronger integration of crops, trees and livestock. These more complex production systems have rebuilt farmers resilience to climate change.

The scale of landscape transformation in Niger is unique, but much more needs to be done to densify and diversify the new agroforestry landscapes. This is urgently needed to intensify agriculture in a sustainable way to feed a rapidly growing population, and to improve the future prospects of young people. There are, however, limits to the expansion of FMNR in Niger. Field observations show that FMNR is mostly practised in areas with high population densities (over 50 inhabitants per km2) and not in areas with fewer people.

Research reported in this review has shown that crop yields increased from 30 to 350 kg/ha depending on tree species, age and density. This contributes to improved food security for families but average yields still remain low: 400-700 kg/ha for millet and sorghum. Given the annual population growth rates of 3-4%, there is an urgent need to continue the process of intensifying agricultural production systems. Agroforestry is a foundational practice in semi-arid and subhumid regions, which helps maintain and improve soil organic matter. This creates the right conditions for adding small quantities of mineral fertilizers, which will help boost crop yields.

The expansion of FMNR is the result of an awareness and the manifest will of smallholder farmers regarding the protection and management of woody species. The adoption is strongly linked to the density of the population (more people, more trees), the type of soil (sandy soils), and the level of education of the head of household.

FMNR is practised by all social categories regardless of gender. Also, the poor and even the extremely poor derive significant income from FMNR through the sale of firewood and other tree products. Women benefit from FMNR because it increases the availability of fuel, which reduces the distances they have to travel to collect it. It also increases non-timber forest products which help improve family nutrition and marketing opportunities.

Farmers protect and manage trees and shrubs that have a positive impact on soil fertility (e.g. *Faidherbia albida, Piliostigma reticulatum*) or species that produce quality fuelwood (*Combretum glutinosum*), fodder (*Faidherbia albida, Acacia spp.*) or fruit (*Adansonia digitata, Bauhinia aegyptiaca*).

The results showed that *Combretum glutinosum, Guiera senegalensis* and *Piliostigma reticulatum* colonize FMNR-based agroecosystems especially on sandy soils because of their adaptability to the climatic conditions, but also because of the ecosystem services they offer.

Studies show that farmers' investment in FMNR is profitable from an economic and financial point of view. The multiple impacts and the perception of farmers that they own the trees on their fields have stimulated the rapid diffusion of this technique. The fact that the presence of trees in fields does not decrease crop yields but helps to increase them, was also a decisive factor.

More than one hundred studies were reviewed (PhD/masters theses, scientific journal papers, research reports) – they all show significant impacts. However, they are almost all conducted in a single year. There is a need for studies in the same villages over longer periods.

The introduction of FMNR has often been accompanied by the creation of village organizations for tree protection and management. They have adopted community regulations against tree cutting and theft, and this new social capital helps to ensure the sustainability of the new tree capital.

The new agroforestry parklands increase the resilience of agricultural production systems to drought years and sequester significant amounts of carbon.

It is necessary to continue the dissemination of FMNR in Niger and to strengthen village organizations for the protection and management of agroforestry landscapes. Several projects in Niger are promoting FMNR, but it is also spreading from farmer to farmer by word of mouth.

The scale of FMNR in Niger is now about 6 million hectares (about 50% of the country's cultivated area). Analysis of satellite images in combination with field visits will allow better monitoring of the scale and dynamics of FMNR.

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