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Assessment of Contour Bunding Technology for Improved Land and Water Management in Mali

Technical Document Produced for the CGIAR Program on Water, Land and Ecosystem (WLE)

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Abstract

This research was carried out in three agro-climatic regions of Mali (Mopti, Koulikoro and Sikasso) to assess contour bunding technology (CBT) for improved land and water management. Reference was made to existing literature and field surveys were conducted following georeferencing and quantification of existing land and water management technologies. Farmers' perceptions towards the use of the most commonly applied technologies were assessed. Results indicate that CBT is widely adopted in farmers' fields to improve the management of land and water resources. CBT was first introduced in 1993 by the Institut d'Economie Rurale (IER) in Mali and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). Up until 2013 the total area of farmland covered with CBT in the three regions was1750 ha. There is a lot of variation in CBT distribution across the three regions with the implication that its adoption increases when the production system is more favourable and there is more rainfall. Farmers have positive perceptions towards the application of CBT in their farmlands. Large proportions of farmers (81%) perceived that soil and water were conserved at a very high or high rate with the use of CBT. In the area of CBT application gullies were reduced at a rate of 73%. Similarly soil fertility was maintained at a rate of 84% at a very high or high rate. Furthermore, with the availability of existing land and water management practices in their farmland 82% of the farmers' responded with success stories mainly to do with better water availability, improvements in crop yield and soil fertility.

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Acronyms and Abbreviations

AMEDD	Association Malienne d'Eveil au Development Durable
CBT	Contour Bunding Technology
CGIAR	Consultative Group on International Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIRADD	Institute International Researche Actions Development Durable
FtF	Feed the Future
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
IER	Institute d'Economie Rurale
NGO	Non Governmental Organization
WCA	West and Central Africa
WLE	Water Land and Ecosystem

Executive Summary

Rainfed agriculture is the backbone of the Malian economy. It accounts for 50% of the nation's GPD and is the primary source of livelihood for 80% of the population. Agricultural productivity however, has been adversely affected by climate variability, water scarcity, land degradation, desertification, poor soil fertility and poor infrastructure. Although there is very little documented evidence, several technologies have been practised in different agro-climatological regions of Mali to improve the productivity of rainfed agriculture.

This study was carried out in three different agro-climatic regions of Mali (Mopti, Koulikoro and Sikasso). The literature was searched and after existing land and water management technologies were georeferenced and quantified, field surveys were conducted. Farmers' perceptions regarding the use of the most commonly applied technologies were assessed. Results indicate that contour bunding technology (CBT) is being widely adopted in farmers' fields to improve the management of land and water resources. CBT was first introduced in 1993 by the Institut d'Economie Rurale (IER) in Mali and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), a French agricultural research centre for international development. Both IER and CIRAD with the participation of small scale farmers promoted a renewed approach of this well-known technique, adapted to the management of individual fields and to agriculture with animal draught. By 2013, the net area of farmland covered with CBT in the three regions was 1750 ha.

The adoption of CBT varies greatly across the three regions. For example, on an average a farmer in the Sikasso region owns 2.7 ha of CBT farmland and the corresponding figures in Koulikoro and Mopti regions are 2.3 ha and 1.1 ha, respectively. This implies that when the production system is more favourable, such as in Sikasso and Koulikoro, and there is more rainfall, CBT is widely adopted. Farmers have positive perceptions towards the application of CBT in their farmlands. The results of the survey show that 81% of the farmers that were interviewed perceived that soil and water were conserved at a very high or high rate when CBT was used. According to farmers' response in areas of CBT application, gullies were reduced at a rate of 73% and soil fertility was conserved at a rate of 84%. Furthermore with the availability of existing land and water management practices in their farmland, 82% of the farmers responded with success stories mainly to do with better water availability and improvements in crop yield and soil fertility.

In addition to studying the adoption of land and water management technologies we made an attempt to understand household food security conditions. While a large majority of households (68%) are food secure, the remaining (32%) are still at risk of food insecurity. Lack of sufficient grain to satisfy household needs as a result of poor land productivity is responsible for 33% of the food insecurity in the area. Other contributing factors are lack of livestock and crop production via small scale irrigation due to insufficient amount of water (25%) and lack of sufficient land to grow more crops and raise livestock (21%). The lack of additional sources of income apart from agriculture is responsible for 21% of the food insecurity.

While the current study helps understand existing farmers' managed technologies and provides household level information it does not provide complete answers to the impacts of small scale practices like CBT applied in farmers' fields. We recommend further research to undersand the biophysical impacts of intervention practices which is associated with quantification of agronomic and livelihood impacts on crop productivity and family incomes. Training needs should be asssessed and the relevant policies and institutions enabled. The need to scale-up the adoption of existing soil-water conservation practices also needs to be considered.

Introduction

Mali is a landlocked country with an area of 1,241,138 km^2. The Sahara and Sahel areas with a rainfall average less than 400 mm occupy nearly 75% of the total area of Mali. The current population of the country is estimated to be 15 million with an annual growth rate of around 2.5%. This population is largely concentrated in the central regions of Bamako, Segou, and Mopti and in the southern region of Sikasso with urbanization rates close to 30%.

The Malian economy relies heavily on rainfed agriculture. The land that is suitable for agriculture represents a mere 14% of the total area of the country. With diverse agricultural practices, locations, climatic conditions and types of productions the agricultural sector is oriented mainly towards market and domestic consumption. This is however challenged by water scarcity, land degradation, long dry spells and increasing dessertification in the south. Above all, unpredictable and unreliable precipitation makes rainfed agriculture a risky undertaking. Hence agricultural yields and water productivity are low, often 10% or less of the potential, in most parts of West Africa including Mali (Andah and Gichuki 2003).

Agriculture and livestock rearing are the main activities in rural areas. Agricultural produce includes diverse food crops, cash crops, fruits and vegetables, legumes, livestock products, forestry products and fishing. In the driest parts (300-700 mm annual rainfall) millet (*Pennisetum glaucum*) predominates as a staple crop. In zones with progressively increasing moisture (700-1100 mm) it is superceded by sorghum (*Sorghum bicolor*) and maize (*Zea mays*: 1000-1200 mm). Also largely present in the production systems are groundnuts (*Arachis hypogaea*: 500-1100 mm), cotton (*Gossypium spp*: 800-1000 mm), cassava (*Manihot esculents, M.utilissima*) and other more water demanding crops and tubers. Rice (*Oryza* spp. or *O. sativa*) is grown in irrigated fields adjacent to the rivers or in flood-recession areas and in lowland plains of the Sudano-Guinean zones. The irregular distribution of rainfall in time and space and the risk of within-season dry spell influences cropping choices. The production potential is considered to be low due to the frequency of droughts and other yield-reducing factors such as low adoption of improved land, water and crop management practices, including pests, diseases and weeds. Small holder farmers get little income from millet and sorghum, the major cereal crops in the region, because of the high risk of crop failure and poor road infrastructure and access to markets in rural areas.

In Mali the history of contour bunding technology (CBT), goes back to the 1990s. CBT was first introduced in 1993 by the Institut d'Economie Rurale (IER) in Mali and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). Both IER and CIRAD promoted a renewed approach of this well-known technology with the participation of small scale farmers, adapted to the management of individual fields and to agriculture with animal draught. This technology has also been widely disseminated in the southern parts of Burkina Faso and in the northern regions of Cote de Ivoire (Gigou et al. 2006). Inspite of its extensive application in these four countries, there is very little documented evidence and research that has identified the areas where this technology has been applied and its effectiveness. Therefore the current study was conducted in three regions of Mali (Mopti, Koulikoro and Sikasso) that represent three different agro-climatic regions defined in the production system to:

- Review and document existing land and water management technologies
- Identify and quantify the adoption of CBT
- Understand farmers' perception towards the performance of CBT and other land management practices

Methods and Materials

Description of Study Areas

The study was conducted in the three regions of Mali (Figure 1) that represent three agro-climatic zones defined in the production system. These are:

- Mopti region: Sahelian zone, districts of Bankass and Koro
- Sikasso and Koulikoro regions: Sudanian zone, districts of Koutiala and Diolla
- Sikasso region: Sudano-Guinean zone, districts of Bougouni, Sikasso, and Yorosso

Production System

In Mali, production systems are categorized based on the amount of rain that falls in a year and the length of that rainy season. The rainy season lasts from June to October. The total annual rainfall and duration of the rainy season which increases from North to South determines several production systems (Figure 2).

The Sahelian-Sahara production system with rainfall less than 200 mm is dominated by pastoralism, while the Sahelian system with rainfall ranging between 200 to 400 mm is an agro-pastoral system based mainly on the drought resistant cereals, millet and sorghum. The Sudano-Sahelian zone has two production systems. In the northern part where rainfall ranges from 400 to 600 mm, common cereal crops like millet and sorghum with a short growing cycle of 90 days are grown. In the southern part that includes the old cotton belt (around Koutiala) with a rainfall range of 600 to 800 mm the production system is more agro-forestry-pastoral, dominated by rainfed crops - cotton and cereals. In these areas cotton production is the main source of income with rotations of sorghum, millet, peanuts and cowpeas in the fields. In the North Sudanian zone with rainfall ranging from 800 to 1000 mm the production system mainly focuses on cotton and maize with peanuts and cowpeas in a few areas. The South Sudanian zone termed as the Sudano-Guinean zone with rainfall greater than 1200 mm has a climate favourable for rainfed rice in the lowlands, and sorghum, cotton and fruit trees are also commonly produced.

Biophysical Characteristics of the Study Regions

The study areas are characterized by strong climatic variations and irregular rainfall that ranges between 200 mm and 1200 mm with coefficients of variation ranging from 15 to 30% (Fox and Rockström 2003; CILSS 2004). Agriculture is predominantly rainfed and depends on three to four months of summer rainfall. The rainy season lasts from May to October, with most of the rain received during August. The growing season starts immediately after the first rain, and lasts a month or two beyond the rainy season. The dry season lasts from October through April. The variability in rainfall poses one of the biggest obstacles to the achievement of food security and poverty reduction in the region. Recent reports (Serigne et al. 2006; UNEP 2012) indicate that rainfall has become less reliable and growing seasons are becoming shorter in many areas.

Soils in the study regions are mainly Arenosols, Lixisols and Acrisols and are inherently fragile, low in carbon and poor in plant nutrient content. Soils lack phosphorus, nitrogen, organic content, and water retention capacity. In addition, the composition of many soils (high levels of sand and silt, and low levels of clay) makes them highly prone to crusting when 'battered' by the heavy raindrops, especially during the first storms (Fox and Rockström 2003). As a result, water runoff rates of 40% of

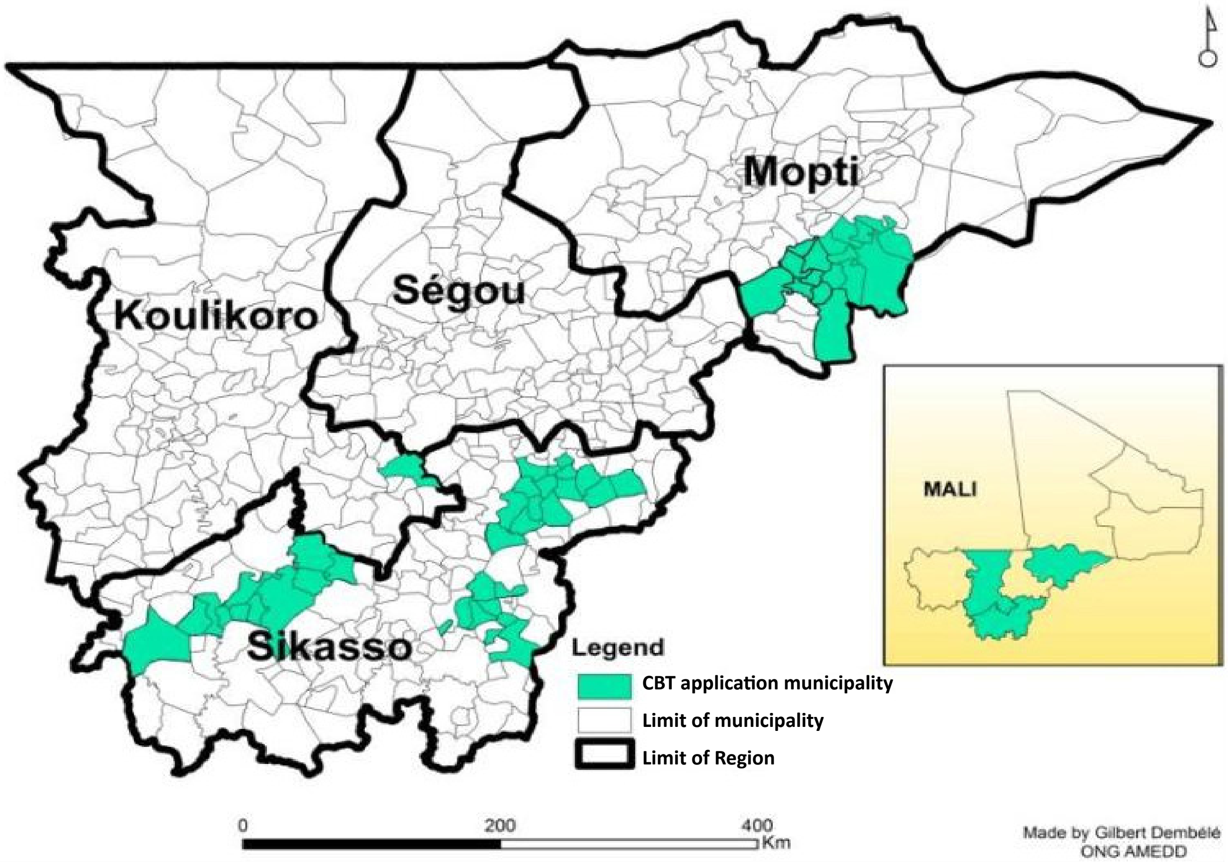


Figure1: Map of Mali and Malian regions where CBT has been implemented from 1993 to 2013.

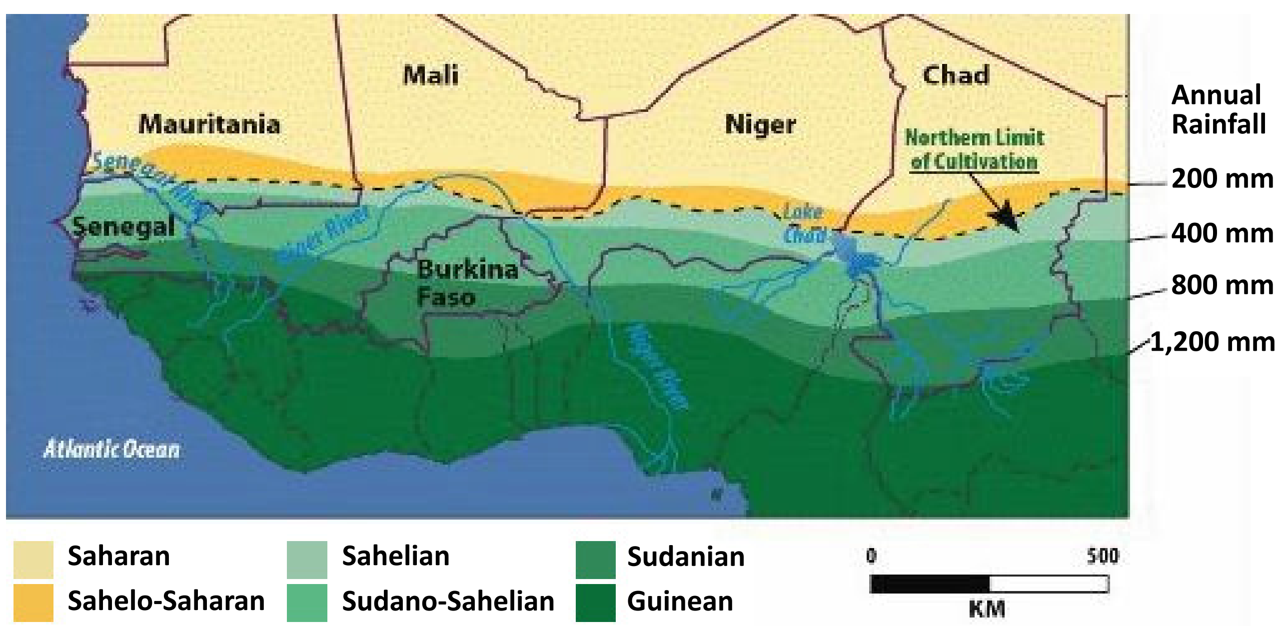


Figure 2: Rainfall limits (mm/year) and climatic description in the Sahel (Source: OECD 2005).

the total annual rainfall are common in these landscapes. In southern parts of Mali for example soil nutrient losses in cultivated soils were estimated to be 25 kg of N $ha^{-1}year^{-1}$ and 20 kg of K ha^{-1} $year^{-1}$ (Van Der Pol 1991).

Development of the Survey Questionnaire

In addition to reviewing the limited literature available on land and water management technologies, a field survey was conducted to identify practices that are most commonly adopted by local farmers, for two months (15 December 2013 to 15 February 2014). Existing local reports from AMEDD indicate that between 1993 and 2013, 748 registered farmers have implemented land and water management technologies in their farming fields in the three regions of Mali. The minimum number of farmers selected for each region to be deemed representative of that region was calculated using equation 1 (Eq 1).

$$n = t^2 . \frac{p.(1-p)}{e^2} \qquad \text{Eq 1}$$

Where:

n is the sample size

t is the confidence interval (in the present case)

e is the margin of error (5%)

p is the probability (50% if unknown)

On considering the confidence interval to be 95%, margin of error to be 5% and probability to be 50% , the corresponding sample size becomes 384. This number however is the sample size for an infinite population. Sample size was calculated for a finite population of 748 people using equation 2 (Eq 2).

$$n' = \frac{Nxn}{N+n} \qquad \text{Eq 2}$$

Where:

n’ is sample size for a finite population of 748 farmers

N is population size (748 farmers)

Hence the minimum representative sample size for the total population of 748 registered farmers becomes 254. Based on this figure, the distribution of sample size was prorated for each agro-climatic zone and municipality as shown in Table 1.

Table 1: Municipalities in the representive sample.

Region (Agro-Climatic zone)	Municipality	Farmers	Percentage within each climatic zone (%)	Sample by areas	Sample by municipality	Non Land and Water Management users
Mopti (Sahelian area)	Bankass	109	78%	48	37	37
	Koro	31	22%		11	11
Sikasso (Sudano-Guinean area)	Bougouni	16	11%	49	5	5
	Sikasso	129	89%		44	44
Koulikoro and Sikasso (Sudanian area)	Dioila	63	14%	157	21	21
	Koutiala	250	54%		85	85
	Yorosso	150	32%		51	51
TOTAL		748			254	254

Within each climatic area, farmers were randomly selected in proportion to their distribution in the different municipalities of each zone. All CBT users have already been identified and each of their fields with contour bunds was geo-referenced with a GPS. The scope of the survey consists of developing survey tool and training enumerators. Initially a sample survey was conducted with a few farmers to validate the survey questionnaire and sampling method. Once the validation was over each enumerator interviewed 5 farmers and geo-referenced 6 ha of farms with CBT per day. In total 102 working days were required to conduct the survey and 108 working days were required for geo-referencing. Ten enumerators were working on the survey and they required nearly 25 days to complete all the interviews and GPS readings.

Farmers without land and water management technologies in their farm fields or those who were not aware of the existence of the technology were also randomly chosen in the same municipalities. They formed the control group with the same sample size as those with available technologies (Table 1).

Results and Discussions

Analysis of Survey Results

Farm size

Farm size classification was done according to the local information obtained from the NGO (AMEDD) working in Mopti, Koulikoro and Sikasso districts. According to this local information a farmer who has a farm size greater than 30 ha and with enough access to agricultural inputs (animal traction, fertilizer input, improved seeds, weed control and market access) is categorized as a *'big farmer'*. A *'medium farmer'* is a farmer with a farm size between 5 and 30 ha and with limited/inadequate availability of agricultural inputs. A *'marginal farmer'* some times called a *'small farmer'* owns a farm less than 5 ha in size with no access to of agricultural inputs.

The largest proportion of the population (83%) lies in the medium farmers' category, 9% of the sampled population are in the category of big farmers and the rest are marginal/small farmers.

There is no difference between medium and small size farmers in the case of CBT and non-CBT users. On an average, 80% of CBT users are medium farmers and the corresponding figure for non-CBT users is 86%. These percentages are relatively close for small size farmers as well. Nearly 8% of CBT users are considered as small farmers and 12% are considered to be big farmers. The corresponding figures for non-CBT users are 7.5% and 6.7%. The analysis indicates that CBT has been adopted by all farmers' categories with higher adoption by medium farmers. Furthermore, big farmers have been adopting CBT in their farm fields to a greater extent than small farmers.

Family size

Families of CBT users are larger in number than those of non CBT users. The maximum number of families using CBT was 140 and the minimum was 8. The corresponding figures for the number of non-CBT using families were 87 and 4 respectively. On an average the number of CBT user families is 27.2 and the corresponding figure for the non CBT users is 21.7. Fifty percent of the CBT users have families that number between 16 and 35 and the corresponding figure for non CBT users is between 11 and 27.

Education

A large majority of the respondents in the sample (68%) are illiterate. Twenty one percent have a primary school level of education and 6% have passed the middle school diploma. Three percent have achieved the baccalaureate or more. There is no great distinction in the illiteracy rate between CBT and non-CBT users. The figures stand at 66.6% and 68.7% respectively signifying the high level of illiteracy in the three regions.

Age

Sampled data concerning family members responsible for field management are nearly the same for both CBT users and non CBT users. In both cases 50% of the population are within the age range of 44 to 65. The remaining 50% of the population lie within the age range of new born to 44 years and 66 to 93 years.

Water resources

A large proportion of the farmers in the sample (73%) have availability of water resources in their locality and 97% have access to a water source every day. The remaining 3% have access to water resources at least every three days. Regarding the quantity of water, 73.5% responded that water is sufficient for their need. However, only 40% of the farmers could increase their irrigated crop area with the available water. The main source of water for household water consumption is from shallow wells (76% during the rainy season and 77% during dry seasons) (Figure 3). This signifies that shallow wells are the primary sources of water for local communities irrespective of the change in seasons. The average time required to collect water for household consumption is 17 minutes during the rainy season and 20 minutes during the dry season. Our field visit assessment shows that the water level in most wells drops to 12 to 15 meters during dry seasons creating difficulties of water access. Introducing water lifting technologies would help reduce the higher requirement for labour in this case.

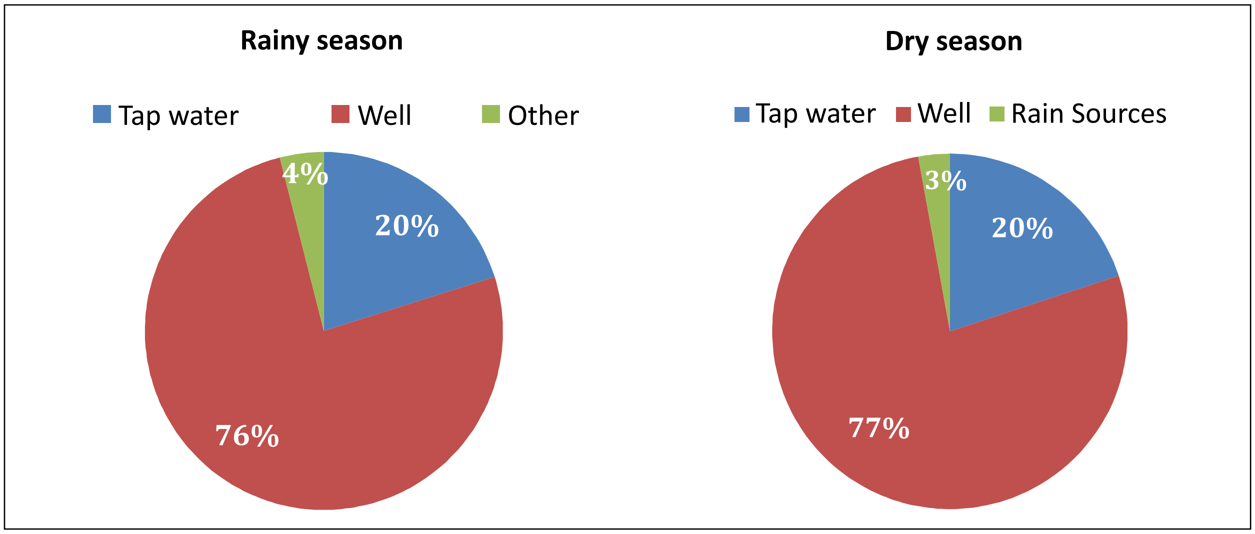


Figure 3: Source of water for household water demand.

During the rainy season the most common source of water used to meet the water demand of livestock is stored water (51%), followed by constructed water pools, ie, artificial ponds (25%) and wells (15%). During the dry period however 81% of the water requirement for livestock comes from shallow wells. Rivers, constructed water pools, and backwater contribute the remaining portions. The time required to collect water for livestock is on the average 47 minutes during the rainy season and 50 minutes during the dry season.

The few practices of irrigation in the study areas utilize directly harvested rainwater during the rainy season and commonly use wells during the dry season. The larger portion of respondents (89%) use harvested rainwater for irrigating crops during the rainy season and 71% use wells during the dry season. The time required to collect water for irrigation is on the average 52 minutes during the rainy season and 66 minutes during the dry season.

Water and soil fertility management structures

Farmers were interviewed to understand whether they have or know about water management structures in their locality and 75.4% responded that they have water management structures in their farmlands. Accordingly eight commonly used and land and water management structures and practices were identified (Figure 4). These are wells, contour bundings, vegetative barriers, bunds composed of stone and earth, contour farming, deep tillage, artificial water ponds, and dams and dikes. Analysis of the results shows that 32% of the total structures counted, are wells and CBT accounts for 26%. These are the two most important interventions utilized for managing water and soil fertility in the regions that were studied.

Vegetative barriers and bunds composed of stone and earth are also utilized and account for 24% of the total structures and practices available (Figure 4). Local farmers also practice contour farming and deep tillage as a means of conserving water and managing the fertility of the soil. These account for 12% of the total intervention in the study areas. There are also a few artificial ponds (water pools) and small dams and dikes constructed to harvest rainwater for short periods of time.

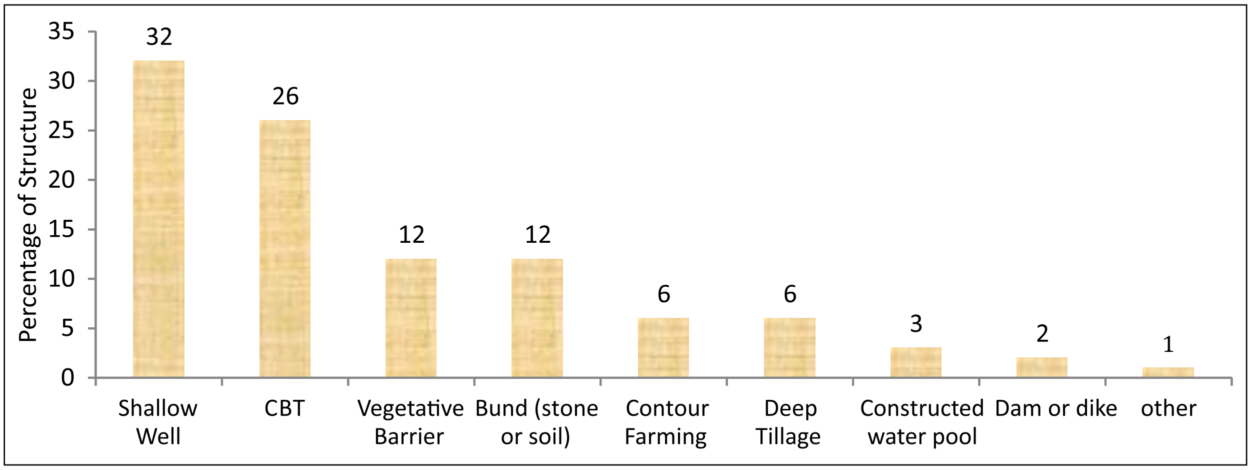


Figure 4: Water and soil fertility structures available in the study areas.

Management structures such as CBT, stone and earth bunds and deep tillage are used by farmers to improve the management of land and water resources. The majority of respondents (96.4%) use CBT in their agricultural fields for crop production. Similalry 93.2% and 83.3% of the respondents use stone or earth bunds and deep tillage respectively for crop production purposes. Artifical water pools are mainly used for livestock water consumption. Eighty five percent of the repondents claimed that dams or dikes are mainly used for crop production primarily for rice fields before cereals are sown in their farm fields.

Farmers perception towards adopted intervention

Apart from shallow wells which are mainly used as water sources for domestic purposes and for livestock, CBT is the most commonly used management structure in farmers' farm fields. A large proportion of respondents (96%) use CBT in their agricultural fields for crop production purposes. Farmers were asked about the extent of change (*Very High, High, Medium, and Low*) they have observed in their area after the implementation of CBT structures. Analyzed responses show that 81% of the farmers believe that soil and water are conserved at a very high or high rate with the use of CBT. 72% of the respondents felt that in the area of its application, gullies were reduced at a very high or high rate. Similarly 85% of the respondents claimed that soil fertility was conserved at a very high or high rate (Figure 5).

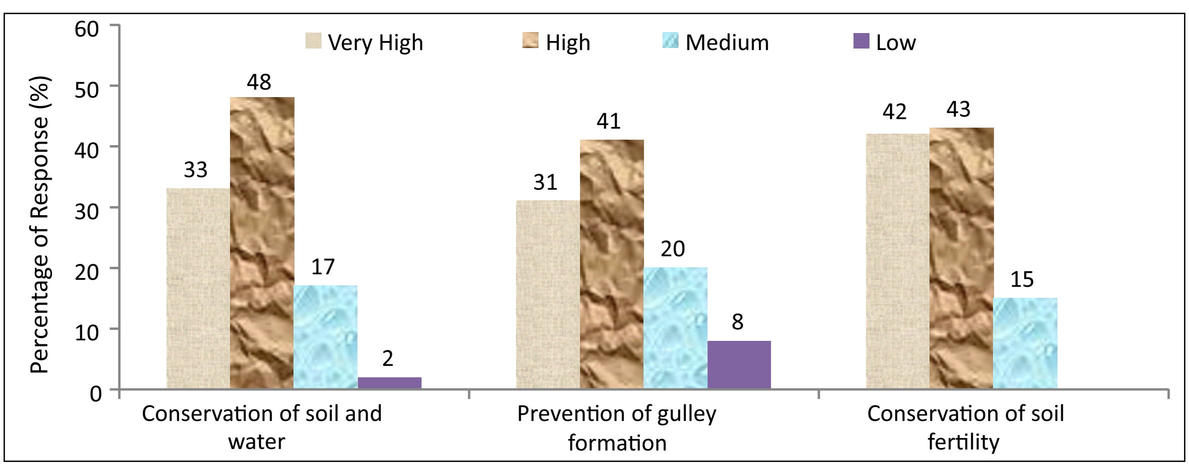


Figure 5: CBT specific efficiency (perception of farmers).

Vegetative barriers (trees and hedges) were assessed as an effective intervention option to conserve soil fertility, demarcate farm fields and prevent the formation of gullies. Figure 6 illustrates that the effects of vegetative barriers were rated as *high* and *medium* for conservation of soil and water (57%), prevention of gullies (58%) and conservation of soil ferlity (58%). Interestingly 78% of farmers rated the practice of putting vegetative bunds as useful for demarcation of farm fields at a *very high, high* and *medium* rate (Figure 6).

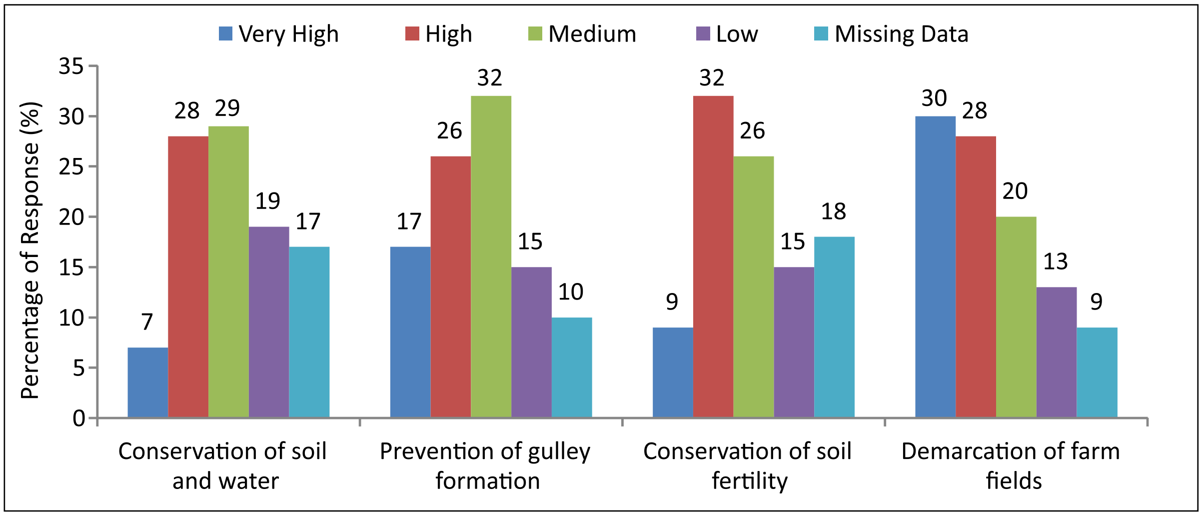


Figure 6: Specific efficiency of trees or hedges around fields (perception of farmers).

Similarly bunds (stone or soil) conserve soil and water at a high to medium rate (58%), prevent gulley formation at a high to medium rate (56%) and conserve the fertility of the soil at a high or medium rate (59%) (Figure 7).

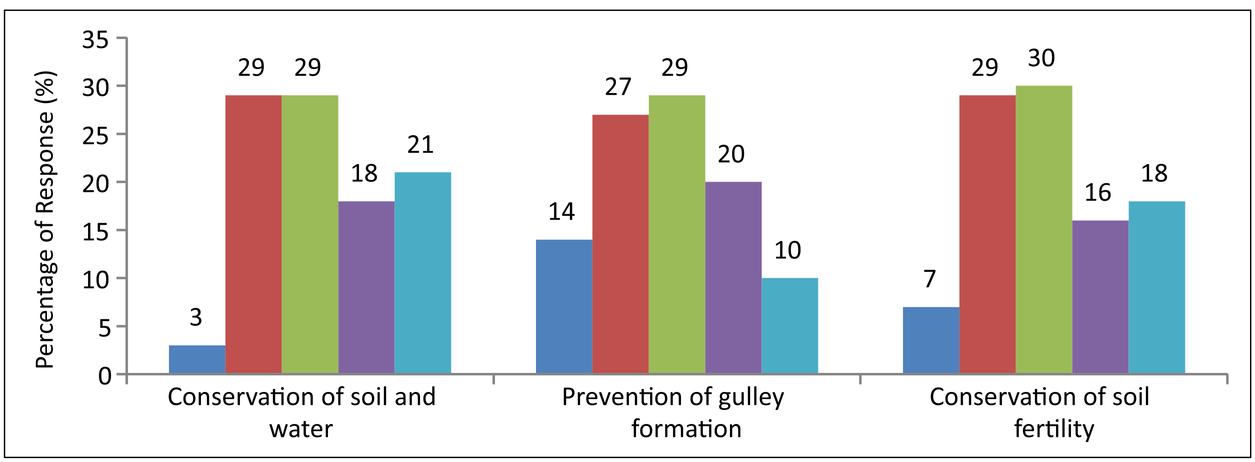


Figure 7: Specific efficiency Bund (earth or stone) without CBT (perception of farmers).

Further with the availability of land and water management structures, 55% of the CBT users and 32% of the non CBT users responded with success stories mainly related to better water availability in their farm fields and improvements in crop yield and soil fertility. Figure 8 shows that 46% of the respondents showed better water availability in their farm fields, 38% indicated that yield has increased and 15% showed improvements in the fertility of farm fields with the availability of land and water management structures.

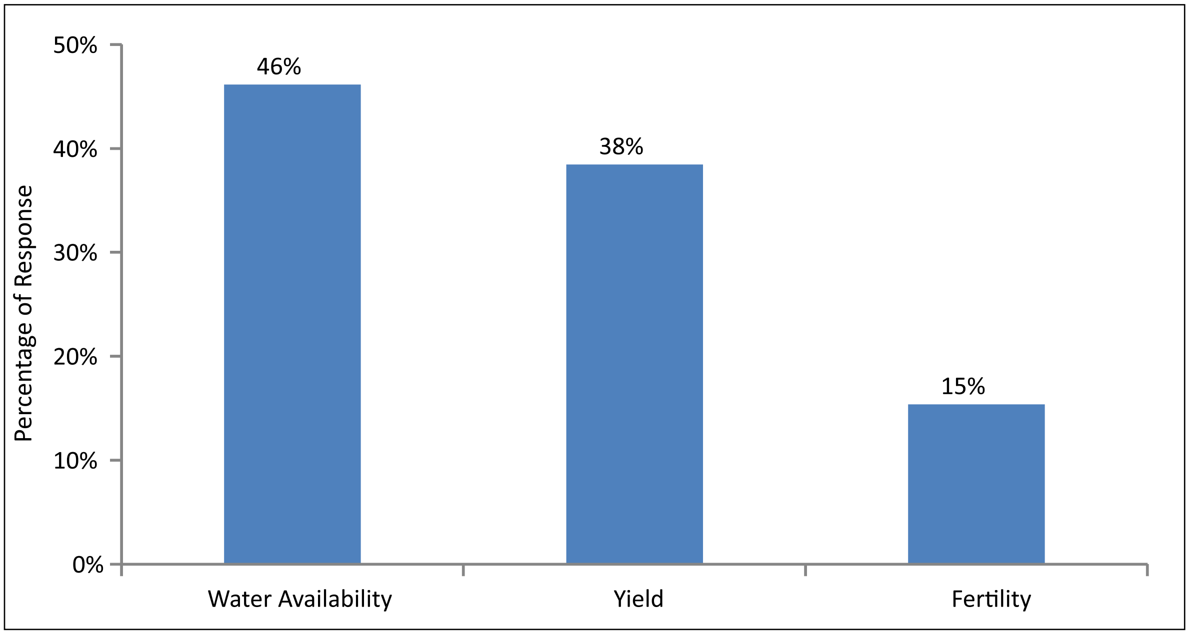


Figure 8: Details concerning success stories various land and water management structures.

Food security

Local farmers were interviewed to understand the level of food security in their locality. While a good proportion of the community (68%) are able to satisfy their own food demand throughout the year (with their own food production) there is a considerable proportion of the community (32%) who cannot satisfy their food demand throughout the year. We tried to understand the causes of food insecurity in the local community and identified the following reasons:

- Lack of sufficient grain to satisfy household needs because of poor land productivity (33%). Inability to produce sufficient grain is associated with poor land and water management practices in the farm fields.
- Lack of livestock and crop production via small scale irrigation due to insufficient amount of water (25%).
- Lack of sufficient land to grow more crops and raise livestock (21%).
- Lack of sources of income other than agriculture (21%).

Review of Existing Land and Water Management Technologies

Apart from conducting the survey questionnaire we reviewed the few existing documents on land and water management technologies. Our review revealed that in addition to the structures and practices included in the survey, several kinds of technology have been practised in different regions of Mali to improve agricultural productivity. The different types of technology are mainly focused on, erosion control, rainwater management and improving soil fertility. Here the different types of technology that are most commonly applied, their agro-climatic suitability, methods of construction, benefits of their adoption and constraints of implementation are presented.

Zai planting pits

Zai planting pits are made to collect runoff in holes which are dug approximately 80 cm apart to a depth of 5 to 15 cm and a diameter of 15 to 50 cm (Figure 9). This technology is applied in low rainfall regions and meets the criteria for three types of conservation practices simultaneously (soil conservation, water conservation, and erosion protection) on encrusted and filled soils. It improves infiltration of the captured runoff and with the addition of fertilizer and organic matter (compost) dramatic improvements in yield can be achieved. This technology can also help reduce evaporation (Fatondji et al. 2005).

The Zai technology is simple and can be carried out by farmers with construction material that is readily available. Experience shows that the technology has been widely accepted by farmers owing to its simplicity and effectiveness (Lee and Visscher 1990). Farmers notice after each rainfall that the earth around the plants remains damp for a considerable length of time. Depending on the hardness of the ground, the input required for the technology ranges between 30 and 70 person days per hectare to dig the holes and 20 people days per hectare for fertilization with manure and composting.

Zai planting pits are used on abandoned or unused land and also in areas that have silt and clay soils. Crop yields resulting from the practice bring a benefit of 100%. Yields range between 0.7 and 1.0 t/ha for sorghum. The major constraint of the technology is the demand for supplementary efforts from the farmer who has to watch over the state of the holes, deepen them and refill them with manure before each wet season. Zai planting pits may also be subject to waterlogging in very wet years (Lee and Visscher 1990).

Figure 9: Farmers in Mali and Burkina Faso apply the Zai technique to recover crusted land in semi-arid regions (Source: *http://en.howtopedia.org/*; downloaded on May 13, 2014).

Stone bunds

Stone bunds have been widely applied in areas that receive an average rainfall of 700 mm, and where stones are available. A single line of stones, or a stone bund, depending upon the availability of stones, is laid along a contour. The resulting structures are up to 25 cm high with a base width of 35 to 40 cm (Figure 10). They are set in a trench, 5 to 10 cm in depth, which increases stability. The spacing between bunds varies but it is usually between 15 and 30 m. For rehabilitation of barren and crusted soils farmers often use a combination of stone bunds and zai planting pits. The contour stone bunds do not concentrate runoff but keep it spread. They also reduce the rate of runoff allowing infiltration, which is further enhanced through the use of the planting pits. Stone bunds are not easily damaged or destroyed by runoff and farmers can be certain to collect sufficient runoff for the production of a crop in a year of irregular rainfall or rainfall that is below average (Critchley 1991; Critchley et al. 1992).

Stone bunding is particularly attractive to farmers because it can be implemented on fields that are already under cultivation. When stone bunding has been used, yields in the first year have been shown to be increased by an estimated 40%. When barren fields are rehabilitated, crop yields of 1.2 t/ha have been achieved in the first year. Application of fertilizers has only rarely been necessary (Critchley 1991; Critchley et al. 1992). Apart from the increase in yield, the technology has noticeable, positive environmental impacts, leading to the rehabilitation of degraded lands and a reduction in soil erosion. The only limitation of this technology is its demand for stones.

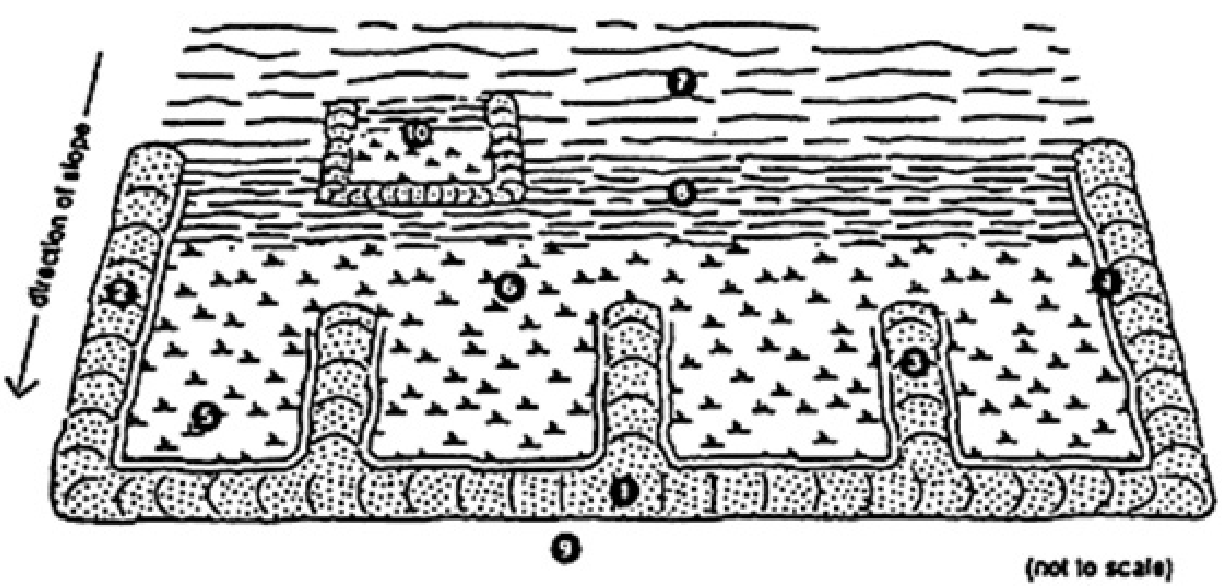
Figure 10: Stone bund in Zelani Village, Koulikoro region of Mali (Source: WFP/Daouda GUIROU, 2014).

Earthen bunds

Earthen bunds are essentially an external catchment, long slope technique of water harvesting appropriate for areas of high intensity and short duration rainfall, which receive 150 to 400 mm rainfall, annually. The structure is shaped like a ‘u’ and farmers build these bunds on their cultivated lands to harvest runoff from adjacent upslope catchments (Figure 11).

The technique is labor-saving and is traditionally farmer-managed. The bunds can be built manually using simple tools. Generally, between 3 and 18 days/ha of work are required to ensure that the system runs efficiently. There is no data on the costs of construction, but they are not believed to be high when the bunds are constructed manually by a farmer (Van Dijk 1995).

The earthen bunding technique allows the production of millet or sorghum crops and reduces land degradation. Socio economic surveys have indicated that the use of this technology has contributed an additional 75% (approximately) to the total household crop production income in the 1980s and 1990s (Critchley et al. 1992; Van Dijk 1995). The only disadvantage with this technology is that lack of a spillway can result in breached bunds.



1. Base contour bund **2. Outer collection arm** **3. Inner collection arm** **4. Shallow channel**
5. Basin **6. Cultivated area** **7. External catchment** **8. Internal catchment**
9. 'Mother' (main structure) **10. 'Child'**

Figure 11: Typical element of the teras water harvesting structure (Source: Van Dijk 1995).

Permeable rock dams

Permeable rock dams are long, low structures across valley floors which simultaneously control gulley erosion while causing deposition of silt, and spread and retain runoff for improved plant growth. This is a floodwater harvesting technique that consists of long, low rock walls with level crests along the entire length (Figure 12).

Contour stone bunds are sometimes used in association with rock dams, especially when the dams are widely spaced. The technology is applicable in arid to semi-arid areas which receive 200 to 750 mm of rainfall. It can also be applied in all agricultural soils - poorer soils will be improved by treatment. Slopes need to be below 2% for water spreading to be most effective (FAO 1991; Critchley et al. 1992).

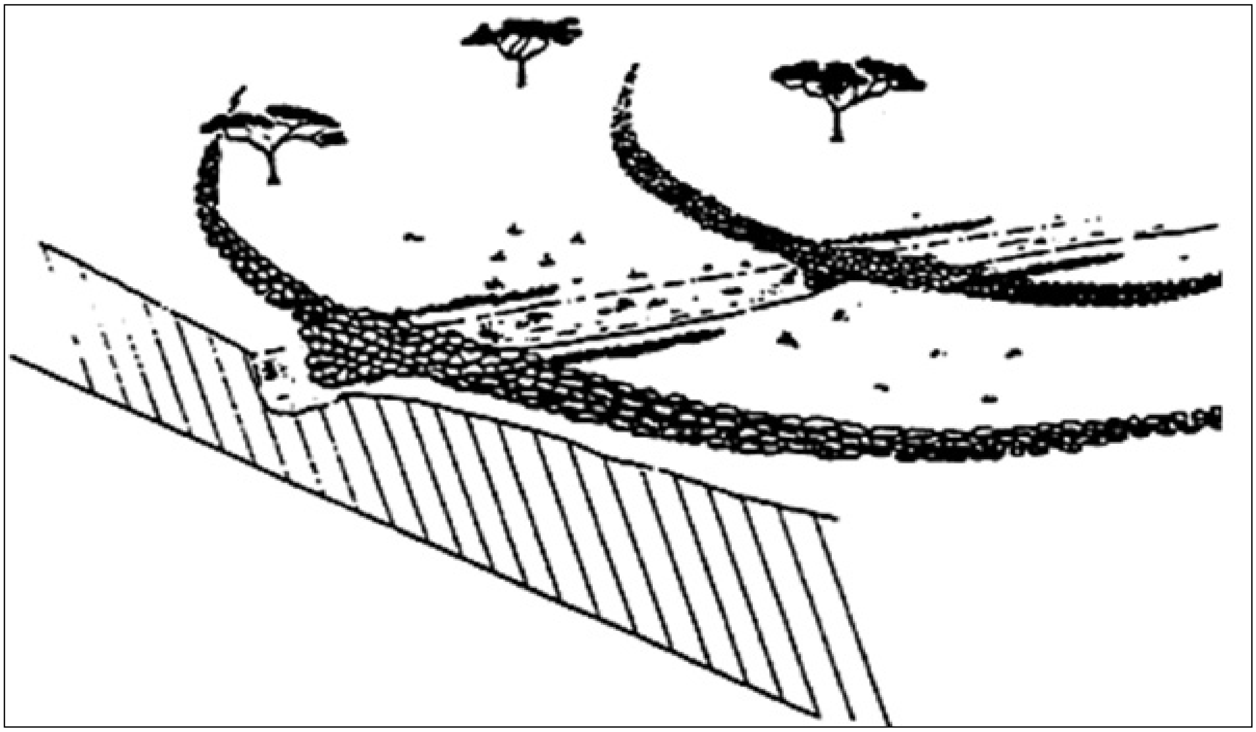


Figure 12: Permeable rock dams (Source: Critchley et al. 1992).

The technology is effective in controlling gully erosion and crop yield can increase considerably as there is more moisture availabile for crops. Yields of sorghum from land restored with permeable rock dams range up to 1.9 t/ha compared with a yield of 1 t/ha from equivalent, untreated land. In addition the control of gulley formation and the increase in silt deposition can have positive effects on a river's course and the quality of its water. Improvement in land management, reduction of runoff velocities and erosive potential and enhancement of groundwater recharge are few of the environmental advantages of permeable rock dams. The main disadvantages of the technology are the high transportation costs, the requirement for large quantities of stone and its site specificity.

Mulching

Mulching involves covering the soil with a thickness of about 2 cm of dry grass, and residues of millet, maize or sorghum. The technology has advantages because of its simplicity and the fact that it is easily controlled by farmers. Moreover, it improves soil fertility through decomposition of plant residues and increases crop yields (Ouédraogo et al. 2007).

Figure 13: Mulching using millet residues in the Sahel.

Contour bunds

Contour bunding technology (CBT) is a well-known method for reducing water run-off and for controlling soil erosion in Mali. The application involves creation of permanent contour ridges, covered with perennial grasses whereby farmers follow the ridges to prepare the farm plot for crop production (Figure 14).

Figure 14: Farm in Southern Mali (Sougoumba village) with contour bunding. Farming practice follows the contour line. Photo credit: Birhanu Zemadim, 2014.

CBT technology has been proven to reduce soil erosion and substantially increase the infiltration of rainwater resulting in increased growth of crops and trees. The ridges increase infiltration of rainwater by up to 10% of the total annual rainfall (800 mm) and between 1 to 2 % in fields with a gentle slope (Traoré et al. 2004).

In Siguidolo, a village located in central Mali, the impact of CBT on food security, natural resource management, and resilience was very apparent. Over 90% of the farmers in Siguidolo have adopted CBT since its first introduction. Before the practice was widely adopted by villagers, rainwater was escaping fields at a 40% runoff rate and precious fertilizer inputs were seeping away (Feed the Future 2012). Other research reports (Gigou et al. 1997; Gigou et al. 2006) reported an increase of crop yields by 30 % and an increase in fertilizer use efficiency by reinforcing farm fields with contour ridges in parts of southern Mali. Similarly the increase in the yield of cotton seeds was reported to be 583 kg/ha with CBT as compared to 227 kg/ha with fertilizer alone (Gigou et al. 1997; Gigou et al. 2006).

In the Omarobougou study site of Koningue commune near Sougoumba village of Mali, Doraiswamy et al. (2007) witnessed better water management and increased crop yield and hence better economic returns for farmers when CBT was used by local farmers. Further the application improved the retention of soil nutrients and increased the yield of cereal crops from 30 to 50%. With similar application, the planting season has been extended by two weeks and local water table levels have risen. The overall advantage was reflected at the household level providing improved household food and incomes (Feed the Future 2012). FtF in association with IER have planned to significantly expand the farmland currently under CBT in the Sikasso and Mopti regions of Mali.

Assessment and Mapping of Implemeted CBT

The total area where CBT has been implemented from 1993 to 2013 in the three climatic zones of Mali is 1751 ha. As shown in Table 2, at a regional level, the highest amount of CBT was applied in the Sikasso region (1452 ha) followed by the Mopti region (152 ha). In the Koulikoro region the total area of CBT applied was 147 ha. The total numbers of farmers using CBT are 545, 140 and 63 respectively for the Sikasso, Mopti and Koulikoro regions (Table 2). On an average, a farmer in the Sikasso region owns 2.7 ha of CBT farm area, a farmer in the Koulikoro region owns 2.3 ha of CBT farm area, and a farmer in the Mopti region owns 1.1 ha of CBT farm area.

On an average in the three regions a farmer has 2 ha of CBT farmland. This implies that when the production system is more favourable and when more rainfall is received (as is the case while moving from the Sahelian region with a mean annual rainfall ranging from 200 to 400 mm to the Sudano Guinean region with an annual rainfall ranging from 800 to 1000 mm) the CBT application is more widely adopted by local farmers.

As shown in Table 2 CBT has been adopted in four districts of the Sikasso region, two districts of the Mopti region and one district of the Koulikoro region. In the Sikasso region maximum CBT was applied in the Koutiala district (806 ha) followed by the Yorosso district (340 ha) and the Sikasso district (279 ha). The least amount of CBT was applied in the Bougouni district (27 ha). In the Mopti, region the Bankass district has more CBT farm area (114 ha) than the Koro district (38 ha). Only one district in the Koulikoro region (Diolla) has a CBT farm with a total area of 147 ha. In these districts the ratio of CBT areas to farmers ranges from 1 in the Bankass district to 3.2 in the Koutiala district signifying a wide range in the adoption of CBT in the different agro-climatic regions.

Table 2: Details of CBT application in the 3 regions of Mali.

Region	District	CBT area in hectare	Number of Farmers	Ratio CBT Area/Number of Farmers)
Koulikoro	Diolla	147	63	2.3
Sikasso	Yorosso	340	150	2.3
	Sikasso	279	129	2.2
	Koutiala	806	250	3.2
	Bougouni	27	16	1.7
Mopti	Koro	38	31	1.2
	Bankass	114	109	1.0
Total		1751	748	2.0

A summary of CBT area in each region, district and municipality is presented in Table 3. Similarly maps showing all the areas where CBT has been adopted were made using GIS software. The maps include geographic locations of region, district, municipality, village and CBT areas. As an example, a map of contour bunding in Gongansso village of Sikasso region is shown in Annex 1.

Table3: Summary of CBT area in each municipality with number of farmers.

District /Circle	Existing CBT area in hectare	Municipality/Commune	Existing CBT area in hectare	Number of Farmers
Bankass	114.1	Bankass central	36.4	31
		Baye	13.1	13
		Dimbal	25.0	25
		Kani Bozon	6.8	8
		Koulogon	11.6	10
		Lessagou	21.2	22
Bougouni	27.0	Bougouni	7.0	4
		Domba	1.0	1
		Faradielé	5.1	2
		Faragouaran	1.2	1
		Kokele	4.3	3
		Kola	3.0	2
		Koumatou	3.0	1
		Kouroulamini	1.4	1
		Zantiebougou	1.0	1
Diolla	147.2	Dieudougou	147.2	63
Koro	38.0	Barapireli	4.1	3
		Bondo	5.0	4
		Dougoutènè II	17.4	15
		Koro central	1.3	1
		Pel Maoude	1.5	1
		Youdiou	8.8	7
Sikasso	279.0	Fama	13.2	6
		Farakala	11.5	7
		Gongansso	6.1	3
		Kaboila	19.9	7
		Klela	47.2	14
		Kouoro Barrage	45.8	31
		Natien	3.4	2
		Pimperna	53.2	27
		Sikasso	57.6	17
		Sokourani missirikoro	19.8	14
		Zanférébougou	1.3	1
Yorosso	339.0	Karangana	91.2	49
		Kiffosso	113.9	47
		Koumbia	92.6	33
		Yorosso	34.6	16
		Zanfigue	6.7	5

Table3...				
District /Circle	**Existing CBT area in hectare**	**Municipality/Commune**	**Existing CBT area in hectare**	**Number of Farmers**
Koutiala	806.9	Guadji Kao	54.5	27
		Kapala	23.6	7
		Koloningue	251.8	64
		Koutiala	6.0	1
		Logouana	68.3	21
		Nafanga	161.5	46
		N'togonasso	7.3	3
		Sincina	9.3	2
		Yognogo	19.1	8
		Zanfigue	24.8	9
		Zebala	180.7	62
Total			**1751**	**748**

Conclusions and Recommendations

The current study was conducted to understand and document existing land and water management practices in Mali through a review of the existing literature, surveys and field visit assessment. Existing literature in land and water management practices at the farm level, though limited, indicates contour bunding technology has been widely applied in farmers' fields. Further, analyzed results in the three climatic zones of Mali ie, the Sahelian, Sudanain and Sudano-Gunian zones showed that eight different land and water management structures and practices have been widely utilized.

Apart from shallow wells that are most commonly used for domestic and livestock water consumption, CBT applied in farmers' field accounts for 26% of the applied technologies. Other techniques like vegetative barriers and bunds composed of stone and earth account for 24% of the total structures and practices available. Farm management practices, especially contour farming and deep tillage account for 12% of the total management interventions in the studied areas.

The areas where CBT has been applied were quantified using GIS technology. From 1993 to 2013 the total area of CBT implemented in the three climatic zones of Mali was 1750 ha. CBT was applied to the highest extent in the Sikasso region (1452 ha) followed by the Mopti region (152 ha). In the Koulikoro region the total area of CBT applied was 147 ha. The total numbers of farmers who have applied CBT are 545, 140 and 63 respectively for the Sikasso, Mopti and Koulikoro regions respectively. On an average a farmer in the Sikasso region owns 2.7 ha of CBT farm area, a farmer in the Mopti region owns 1.1 ha of CBT farm area and a farmer in the Koulikoro region owns 2.3 ha of CBT farm area. On an average in the three regions a farmer has 2 ha of CBT farmland. The analysis shows that when the production system becomes more favourable and when more rainfall is received (as is the case while moving from the Sahelian to Sudano Guinean region) the CBT application is more widely utilized.

Farmers have positive perceptions towards the application of CBT in their farm fields. Of the 254 farmers that were interviewed, 81% believed that soil and water were conserved at a very high or high rate with the use of CBT. Furthermore, in the areas of CBT application, gullies were reduced at a very high or high rate (72%) and soil fertility was conserved at a very high or high rate (85%) according to farmers' responses. In addition, with the availability of existing land and water management structures, 55% of CBT users and 32% of non CBT users responded with success stories mainly on better water availability in their fields and improvements in crop yield and soil fertility.

The study was extended to understand the level of food security in the three regions. While a good proportion of the community (68%) are able to satisfy their own food demand throughout the year (with their own food production) there is quite a considerable proportion of the community (32%) who are unable to satisfy their food demand throughout the year. Major reasons for food insecurity are lack of sufficient grain to satisfy household needs because of poor land productivity, lack of livestock and crop production via small scale irrigation due to insufficient amount of water, lack of sufficient land to grow more crops and raise livestock, and lack of sources of income other than agriculture.

While the current study helps understand the existing technologies of land and water management in Mali it does not give complete answers to the impacts of small scale practices like CBT applied in farmers fields. We recommend further research in order to:

Assess and quantify, the biophysical impacts of land and water management practices like CBT through hydro-meteorological monitoring stations and any developing relationships between rainfall, streamflow, soil moisture, erosion rate, and shallow groundwater levels.

Quantify the agronomic and livelihood impacts of CBT on crop productivity and family incomes.

Assess training requirements and enable policies and institutions for scaling-up the adoption of CBT and other soil-water conservation practices.

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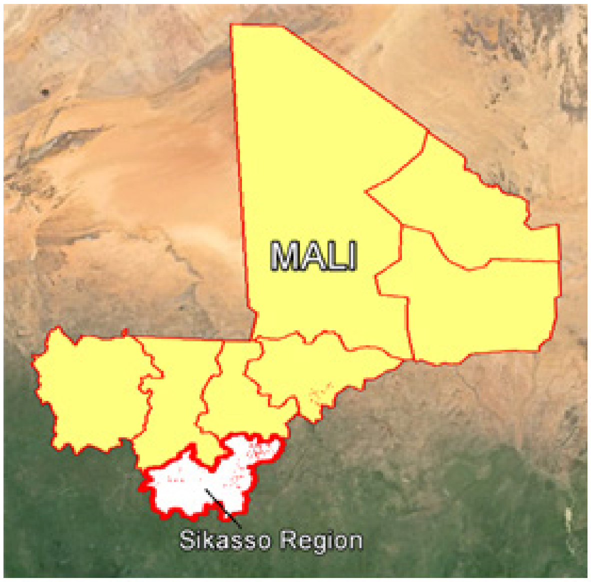
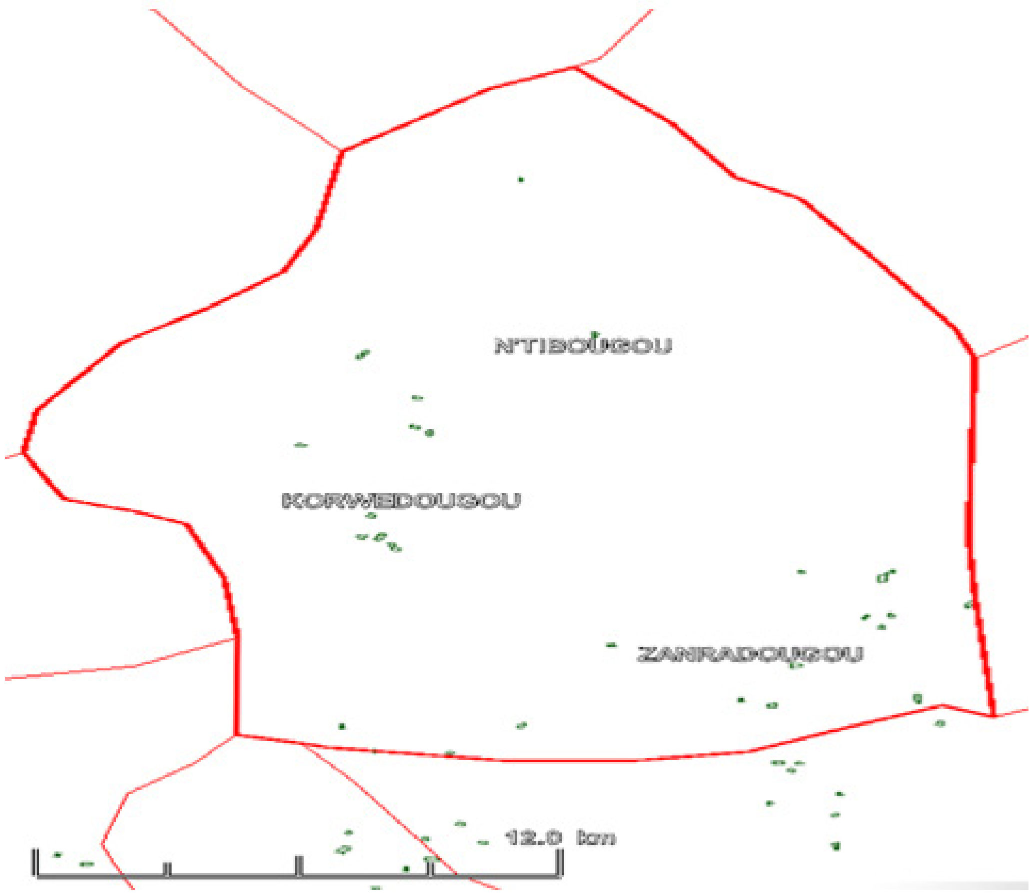
Annex 1: An Example Map of Contour Bunding in Gongansso Village of the SikassoRegion.





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