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Measuring the Productivity from Indigenous Soil and Water Conservation Technologies with Household Fixed Effects: A Case Study of Hilly-Mountainous Areas of Bénin

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Abstract

In this paper we examine the productivity of indigenous soil and water conservation investments in the Boukombé region in Northwest Bénin, using an in-depth survey among 101 farmers on farm inputs, outputs, and SWC investments. We show that positive effects of SWC investments are only observed if one controls for household-specific constraints. We use a production function approach to relate SWC to farm output, and we control for observable and unobservable household characteristics with household fixed effects. The results show that (1) there are large productivity effects of indigenous SWC investments in the Boukombé region of Benin, (2) there is a positive interaction between fertilizer use and SWC on productivity, (3) the productivity of SWC has an inverted U-shape in plot slope. Misspecification tests for omitted variable bias, endogeneity bias, and selection bias are performed and show that the results are robust.

1. Introduction

There are still few studies to assess returns from indigenous mechanical and non mechanical land conservation structures found in many areas of LDCs (stone bunds, tie-ridging and ridging, raised beds, etc.), particularly in Africa. Byiringiro and Reardon (1996) have examined the effects of soil conservation investments on farm productivity in Rwanda, and found that farms with greater investments in soil conservation have much better land productivity than other farms. Place and Hazell (1993), using data from Ghana, Kenya and Rwanda, were left with very disappointing results; except few cases, they found land improving investments to be an insignificant factor in determining yields. Similar results are also reported by Hayes *et al*. (1997) in Gambia. Household-specific constraints (credit constraints, labor constraints due to rising migration opportunities) as well as the lack of adequate data were often indicated as plausible sources of the unexpected results.

In this paper we examine the productivity of indigenous soil and water conservation investments in the Boukombé region in Northwest Bénin, using an in-depth survey among 101 farmers on farm inputs, outputs, and SWC investments. We show that positive effects of SWC investments are only observed if one controls for household-specific constraints. We use a production function approach to relate SWC to farm output, and we control for observable and unobservable household characteristics with household fixed effects. The results show that (1) there are large productivity effects of indigenous SWC investments in the Boukombé region of Benin, (2) there is a positive interaction between fertilizer use and SWC on productivity, (3) the productivity of SWC has an inverted U-shape in plot slope. Misspecification tests for omitted variable bias, endogeneity bias, and selection bias are performed and show that the results are robust.

The structure of this paper is as follows. In section 2 we start with a discussion of the role of indigenous soil and water conservation techniques for agricultural intensification. It will be argued that there is a strong rationale behind the promotion of indigenous SWC techniques in less-favored areas where natural conditions are unfavorable and infrastructure provision often highly insufficient. In section 3 we discuss the different types and adoption rates of the most important indigenous SWC techniques that can be observed in the Boukombé region of Northwest Bénin. In section 4 we use a production function approach to relate farm output to inputs and SWC investments to measure the productivity of indigenous SWC investments. Section 5 concludes.

2. Farmer-based innovations and modern technologies for agricultural intensification in LDCs: key issues and perspectives

Many observers have stressed that there are few signs of technological progress in many rural areas of LDCs since most of the farmers in these areas are still unable to make the switch to industrial way of farming using highly mechanized tools, chemical inputs, high-yielding varieties, modern irrigation systems, and other techniques, most of which have been supplied to them during the green revolution period. The extremely low adoption rates of these new methods, techniques and tools, especially in the less-favored areas in Africa, have renewed the interest of development workers and researchers in farmer-initiated innovations (Spencer, 1994; Fan and Hazell, 1999). It has then been found that several indigenous technologies are already being implemented more or less intensively to combat erosion and control soil fertility, such as ridging and tie-ridging, silt traps, stone-walled terraces, stone bunds, use of organic fertilizer (green and farmyard manure), and tree planting and protection. Some of these land investments were already in use in the more densely populated parts of Sub-Saharan Africa prior to the colonial period (Allan, 1965; Gleave and White 1969; Morgan 1969; Okigbo 1977; Richard, 1961; Miracle, 1967; Pingali and Binwansger 1984 & 1988; Templeton and Scherr, 1997).

Many of these indigenous types of soil and water conservation methods and techniques have been found in Boukombé already in 1959 by the first French soil scientists Mr. Fauck and Mr. Maignien, who were appointed to evaluate the extent of soil degradation, to analyze the available soil conservation techniques and to suggest new methods to arrest erosion and improve soil fertility in the area. They reports that stone bunds and ridging were widely used by farmers although they strongly argued that these should not be considered as conservation techniques: "The Sombas hardly apply soil conservation methods", they reported. We quote the main conclusions of their study (Fauck et Maignien (1959, p.5) - translated from French):

> *……The Sombas hardly apply any indigenous soil conservation methods. The existence [in the area] of stone bunds and pseudo contour bunds might likely delude us. In fact, these [structures] are nothing other than simple heaps of stones collected from the fields. Often, the bunds are constructed following the direction of the highest slope. Some sporadic horizontal bunds are observed but they hardly reduce the water run-off; they often have many breaks which are filled up by various thin materials from the field.*
> *…..The traditional crops are sorghum and hungry rice [which are] grown in every part of the territory where enough space for cultivation is available. All the hills are cultivated and it is likely that nothing is able to speed down the population pressure [on the land resources]. Sorghum is planted on ridges; the more deficient is the drainage the higher are the ridges….. The duration of the fallow is very short.*

It is worth remembering that the key conceptual lines of the first and most famous Integrated Agricultural Development Project implemented in Boukombé in the sixties

(1963-1969), the so-called '*Projet SEDAGRI*[1] were drawn on the basis of the conclusions of this report. And indeed, no attention was given to the indigenous soil conservation techniques by the project following more or less the recommendations of the soil scientists Fauck and Maignien. The project thus put all its efforts into the construction of contour bunds ('*banquettes*') made by means of heavily mechanized equipments and hired local labour. The second largest activity of the project was the dissemination of the use of chemical fertilizers. In spite of these activities, they did not prevent the region of suffering of severe food insufficiency in the late seventies and early eighties.

The approach used in the project finds its roots in the Malthusian view that farmers in LDCs are unable to show sufficient capacity of innovativeness when confronted with population pressure, degradation of natural resources and crop yield decline. This line of thought was followed by almost all colonial officers and until a very recent period by almost all agricultural extension and research administrations in LDCs. To this view was always opposed the Boserupian view of agricultural development, according to which farmers in LDCs are extremely 'dynamic', and the techniques and methods they develop to cope with soil degradation and correct for crop yield decline are the most appropriate ones both on economic and sustainability grounds (Richards, 1939 and Nadel, 1942 cited by Boserup, 1965; Reij and Scoones, 1996). They strongly argue that local invention and on-farm produced conservation inputs should be far sufficient to improve significantly land and labor productivity in tropical agriculture. The reasoning is based on the deep-rooted belief that "output of land responds far more generously to an additional input of labour than assumed by neo-Malthusian authors" as suggested by Boserup (1965, p.14) and consequently

[1] SEDAGRI is the name of the French Consultancy firm which was in charge of the implementation of the project. The project was implemented 3 years after the Indepedence in 1960 and by that time the

sufficient increase in farm output could be obtained without applying large quantities of industrial inputs even in case of very rapid rate of population growth. It is this argument which gives birth in the last two decades to the concept of Low External Input Agriculture (LEIA). This line of thoughts have been reinforced in the early 90s owing to worldwide empirical evidence about soils and environmental damage caused by the excessive use of chemical fertilizers and pesticides, irrigation water and tractorization; the literature reports many examples of waterlogging and salinization, fertilization and pesticide contamination of water, increasing pest resistance and resurgence, habitat loss, soil erosion and tapering or perhaps declining yield potential (Costin and Coombs, 1982; Singh, Singh and Bal, 1987; Subba Rao, Chowdry and Venkata Reddy, 1987, Chopra, 1989, Randall, 1981; Pingali and *al*, 1990; Scherr and Hazell, 1994; Fan and Hazell, 1999).

Recently, an intermediate line of thoughts has emerged which suggests a combination of both extreme schools. According to the new propounded approach, strengthening both agricultural productivity and sustainable resource management requires complementarity in technology use. Local technical invention should be catalyzed and supported and this is particularly necessary in less-favored areas where natural conditions are unfavorable and infrastructure provision (roads, education, communications, research and extension, etc.) often highly insufficient (Scherr and Hazell, op. cit.). Nevertheless, it is also implicitly or explicitly assumed that innovativeness on the part of the farmer would have little impact on productivity growth and thus in case of rapid population growth it would hardly ensures food security. 'Rapid growth in food output would be achieved only when farmer-initiated innovations are complemented by science- and industry-based inputs, such as high-

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national agricultural extension and research administration was not yet created.

yielding varieties, fertilizers, pesticides, and similar' (Pingali and Binswanger in Lee et al., 1988).

The above discussions suggest that it seems rational to start always by exploring the potentiality of the local technical knowledge and invention (since they are likely to be the most accessible ones) and then move further only when their capacity in enhancing farm output is fully assessed. By adopting such sequence in policy implementation, it might likely be possible to find an optimal mix of additional/new methods, techniques and tools at more favorable private and social costs/benefits ratio. Bunch and Lopez (1995) report examples of extension programs in hilly-mountainous areas of Central America which have attempted to accelerate the process of agricultural intensification by strengthening local capacity for innovations (attitudes, institutions, skills in experimentation) rather than focus on technology introduction. Unfortunately, tools for assessing the performance of the farmer-initiated soil conservation techniques remain very weakly developed and empirical evidence still rare (Boserup, 1965, Scherr and Hazell, 1994) although it is generally assumed that they improve the productivity of the land.

In section 4 we elaborate an empirical assessment of the impact of the traditional land improving techniques by using plot-level data derived from a questionnaire survey conducted in 1999 in Boukombé (Northwest of Benin). Regression results indicate that most of these techniques do yield high returns but only when one corrects for household fixed effects. First, however, we discuss the characteristics of the indigenous soil and water conservation techniques in the Boukombé region in Northwest Bénin.

3. Characteristics and adoption of the indigenous soil and water conservation techniques in Boukombé.

Only very recently, with the start of the World Bank project PGRN (*Projet de Gestion des Ressources Naturelles*) in 1994, have indigenous soil and water conservation techniques been put on the agricultural research and extension agenda in the Boukombé region.The Bénin agricultural administration has always been reluctant to initiate research on traditional land improving techniques in this area. This reluctance is likely fully in line with the recommendations of Fauck and Maignien (op. cit.).

The PGRN project has conducted a large study on the indigenous SWC techniques in Boukombé in 1994 (Kodjo *et al.* 1995). However, detailed data on the rate and intensity of adoption as well as the spatial distribution of these techniques have not been reported. In order to assess these important aspects and also to evaluate the potential of these techniques in enhancing farm output, we used an in-depth survey among 101 randomly selected farm households in four villages (Takouanta, Okouaro, Kounakogou and Koutagou). Village surveys (PRA) were conducted in July-August 1998 supplemented by a questionnaire survey in January-February 1999. Data on household characteristics, production systems and soil conservation activities were collected for the crop season 1998/1999. Table 1 briefly describes the productive resource endowments and the major sources of income of the households included in the study sample. The vast majority of the households rely mainly on crop production for their subsistence. The market value of the annual gross output from that activity is low (FCFA 111,700 or US$151.31, on average). However, most of the households are also engaged in small-scale livestock farming (guinea fowl, poultry, pig, duck, etc.). About one-third of the households also earn additional income from the sales of gathering products and fruits (firewood, shea nuts, cashew nuts, mangoes, etc.), non-farm employment (pottery, small-scale processing of gathering products and agricultural crops) and remittances. Many households own some goats, sheep or cattle mainly for consumption-smoothing purposes; about 71% own 5-6 goats or sheep and 41% have 4 cattle, on average. Until recently, official sources often qualified the economic situation in Boukombé as absolutely desperate; this view was commonly shared in the sixties and seventies. Indeed, households in the area face a particularly hostile natural environment; the total area of the sub-prefecture is 1036 sq. km of which only one-third is cultivable for a total population estimated at 69,852 in 2000 (INSAE, 2001; Babatoundé and Sounkoua, 1996; CARDER, 1999). Most of the soils are very rocky and increased population pressure has substantially reduce the quality of a large proportion of the cultivable land.

In the sixties and early seventies, resettlement programs have even been initiated in order to remove part of the population from the most hostile fringes of the region, but most of these initiatives have failed; many people refused to leave they homeland (Natta, 1999). In the second half of the 1990s, official sources indicate an improvement in the growth of the cereal production and this has renewed the interest of policy-makers in the agricultural potential of the area. Often, three reasons are commonly stressed to explain the recent trends. First, there has been a dramatic increase in the adoption rate of maize, which is being substituted for some traditional crops such as hungry rice; the area of maize has been multiplied by a factor of 12 between 1969 and 1999. Second, there has been a high increase in the rate of application of mineral fertilizers; in 1999, 74,900 kg of fertilizers were purchased in the sub-prefecture while in 1978 only 26,659 kg were used. Third, a large adoption of animal traction has been recorded in recent years in the most fertile areas of the sub-prefecture; the number of ox-ploughs was 167 in 1996 while only 3 oxen could be found in the area in 1978 (CARDER, 1969-1999; Adégbidi *et al.*2001).

In the framework of this research, we found that many indigenous SWC techniques are at the heart of the farming systems in the study area and, therefore, we postulated that they may also have affected the performance of the agricultural production. Indeed, in all four villages, farmers were found to be well accustomed to the broad patterns of traditional land improving techniques observed in most of the hilly-mountainous areas around the world: structural conservation measures, tie-ridging and ridging, water catchments, and biological measures (use of manure, fallowing and crop sequencing). Table 2 gives the rate and the intensity of adoption of each of these techniques per village. We also show in the same table the level of application of the exogenous SWC technologies introduced by the extension and research administration as well as projects[2] financed mainly by international organizations; these include mainly contour bunds, contour ploughing, tree planting, composts, mineral fertilizers, and recently construction of live barriers (made of *vetiveria zizanoides*) has also been tested. We discuss each of these techniques in turn, focusing particularly on the indigenous techniques.

Stone bunds

Two variants of this device are applied in the area and known under the local names *yikouati* and *yekotrindie*. They are usually found in villages where rocky soils are predominant, namely Koutagou and Takouanta. In these two villages 55 respectively 59% of the plots have stone bunds. The first variant (*yikouati*) is the usual type of stone bunds and the most popular (see figure A.1 in appendix A). The

[2] The following projects were implemented to prevent soil and environmental degradation in Boukombé: SEDAGRI [1963-1969], UNSO [1984-1989], UNDP/FAO [1986-1990], PGRN [1995-

direction of the bunds on a given plot depends on the site-specific conditions as appreciated by the farmer; however, for the majority of the plots (51%), the bunds are parallel to the slope; on the remaining plots, either the bunds are perpendicular to the slope (27%) or there is no predominant direction (22%); in the latter case, parallel as well as perpendicular bunds can be observed on the same plot. On average, a bund is not higher than 30-50 cm and the distance between the bunds does not exceed 7 m, except on very steep plots where the distance is typically smaller. Plants are grown between the bunds by using various ridging techniques. The second variant of stone bund (*yekotrindie*)[3] is found only in specific areas mostly on very rocky soils at the summits of the mountains where the usual stone bunds (*yikouati*) can hardly be constructed (see figure A.2 in appendix A). In this variant, the plot is cleared of stones and divided in small pieces surrounded with stone walls. Most of these pieces of plot have a rectangular form, however, few cases of circular form are also reported; the average length is 5-6 meters for 2-4 meters width. The height of the wall does not exceed 35-40 cm on average. The plant are grown in the space created inside these pieces of plot. The reasoning behind this device is that water will be trapped and its infiltration will be facilitated. Newly constructed bunds can hardly be found in Boukombé; most of the farmers have inherited the bunds from their parents together with the plots. However, in recent years many cases of reconstruction of bunds are reported and they have been motivated by the increase in the rainfall intensity and land scarcity; a reconstruction work consists in changing the orientation (direction) of the bunds; it could also means a removal of some bunds in order to recover more cultivable land while the height of the remaining bunds is increased. The maintenance

1998], PILSA [1996-1998], SNV [1995 up to now], Sasakawa Global 2000 [1992-1996]).

[3] This second variant is also given the name '*nids d'abeilles'* ('honeycomb weave') by the research unit of INRAB (Institut National des Recherches Agricoles du Bénin) who did the inventory of the land conservation techniques in partnership with the World Bank Project (PGRN, Projet de Gestion des

of the stone bunds is done on a yearly basis by hand using an axe. It requires mostly labor inputs (34 man-days per hectare, on average[4]). It has often been observed that many farmers add sand or wild grass (after weeding) to the bunds to make them longer lating.

The functions of the stone bunds, as perceived by the farmers, are three. First, it is a means to speed down the run-off. Second, it helps for clearing the land from stones. Third, it secures property rights on the land.

Tie-ridging and ridging

Tie-ridging and ridging are widely used in all the study villages and might be seen as the most popular soil and water conservation technique in the region. It is broadly used and more elaborated in the plains where gravelly soils and light to high slopes are predominant (Kounakogou). Most of the crops are planted on ridges except yam which is grown on mounds (in the bottomlands).

Two versions of the tie-ridging techniques are available. The first one is known under the local name '*spenpen*'[5]; in this version, most of the ridges are parallel to the slope but they are intersected by a certain number of bunds which are perpendicular to the slope (see figure A.3 in appendix A). The higher the length of the slope, the more perpendicular bunds are constructed. If stones are available on the plot or can be found in its neighborhood, they can be used to reinforce the bunds. In some areas, plants are also grown on the bunds. Across all villages, 34 percent of the

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Ressources Naturelles).

[4] The average labor requirements for the maintenance is estimated on a plot basis and this represents the average for each or both variants of stone bunds (*yikouati and/or yekotrindie).* Note that both of the indicated variants of stone bunds are often combined on most of the plots; the number of plots with only *yekotrindie* are very few, but its maintenance often requires more labor (2.5 times the indicated average if one considers only the portion of land occupied by this device).

[5] This device is called '*billonnage cloisonné*' in French.

plots have the first type of tie-ridging, of which most can be found on plots in Kounakogou (72 percent).

The second version of tie-ridging is often found on steep plots and can be found on 5 percent of the plots (see figure A.4 in appendix A)[6]. Like the former version, the ridges are also parallel to the slope, however, there are at least two rows of ridges on each plot instead of one row as observed in the previous version. This gives the possibility to use any ridge from a given row to tie up two successive ridges in the neighboring row. This version might have been developed in recent years to replace the traditional type of ridging often used on high slopes in the area; traditionally, the ridges constructed on high slopes in the area were always parallel to the slope; there was no tie-ridging in such plots. The reasoning behind the use of parallel ridges is that pluvial waters will quickly be evacuated along the furrows and the plants will be protected. Similar reasoning explains why most of the ridges found in the area are parallel to the slope and not perpendicular as recommended by extension and research workers. The switch to tie-ridging might have been motivated by the gradual increase in the rainfall intensity in recent decades. However, it can also be viewed as an adaptation of the recommendation of the extension administration. There is also an increasing number of plots on which perpendicular ridges can be found.

Unlike the stone bunds (or water catchments -see further), the ridges are fully reconstructed every year. The reconstruction work consists in removing the old ridges and building new ones in the furrows (i.e. every year, ridges are substituted for furrows). Tillage and ridging are often done simultaneously, consequently it is unlikely that a distinction can be made between labor inputs for tillage and ridging.

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[6] It is called '*billonnage en quinconce'* in French

Most of the farmers do not perceive the above described physical measures (stone bunds, tie-ridging and ridging) as having a direct effect on the yield. Rather, they view them as a means to control the run-off and improve the process of water infiltration and thus water uptake by the plants. Consequently, the effect on the yields might be indirect. However, their effect on the total farm output might be great since they make possible to bring under cultivation the land which, otherwise, can never be cultivated (the so-called '*marginal land*').

Water catchment

It is a well-known device in all villages where light to steep slopes are predominant. Water catchments can be found in 25 percent of the households and on 9 percent of the plots. They are constructed near the compound (*tata*) of the farmer and it is mainly designed to receive the fluvial waters (see figure A.5 in appendix A). The two elements of this device are a canal connected to a basin (with raised borders). The length of the canal is variable depending on the slope length (7 meters, on average). The diameter of the basin is around 3.5 meters for 0.76 meters depth. The oldest catchment was built in 1979 and the most recent one in 1998 for our sample. On average, it costs 2.25-5 man-days to build a catchment, however, the construction work is very hard and can last many more days on rocky soils. The catchment is maintained every year and this requires 2-4 man-days. Construction as well as maintenance works are done by hand using hoe, mattock and various makeshift instruments to remove the sand out of the basin.

The water catchment is called *dikononkotri* or *dikononkoua* by the villagers[7]. It is designed to avoid destruction of the homesteads (*tata*) by protecting against

[7] This device has been given the name '*collecteur d'eau*'

flooding not only the homestead of the owner but also the neighbouring homesteads; however, its major effect is to contribute to speed down the run-off on the plots next to the homestead (home gardens). Home gardens represents more than a quarter of the farmer's holding in Boukombé and they are often ranked by the farmers as the most valuable land because of more regular fertilization with animal manure and household refuse. In many cases, plants are also grown on the borders of the basin (sorghum, maize, legumes), however, it serves more often as nursery where millet is primarily grown for replanting.[8]

To achieve improvement in the yields, Boukombé's farmers, traditionally, rely on the use of animal and green manure, fallowing and crop sequencing.

Animal manure

Animal manure is used by 14 percent of the households and mostly applied on the plots next to the homestead (*tata*). The manure is supplied to the fields in two ways; either, it can be collected and transported to the fields, or the animals are parked on the plots which are to be fertilized; a fallow land can receive the animals during a whole day in the rainy season; however, on the permanent fields they can only be parked in the night and left for grazing during the rest of the day either in the bush, or on the fallow land during the dry season. In both cases, the quantity of manure as well as labor inputs can hardly be measured because of the high fragmentation of the whole process of fertilization. It is unfortunate to note that in recent years the intensity of the use of animal manure has strongly declined according

[8] The widespread method for growing millet in the area is by replanting. The reasoning is that the weather risks will be reduced by cutting down the period of vegetation on the field. Note, that the rainfall is very irregular and volatile in the area, with a clear tendency towards a shortening of the rainy season and worsening of the intra-annual distribution of the rains in recent years.

to many interviewed farmers either because the animals have been stolen or decimated by diseases.

Green manure and mulching

Mainly crop residues and wild grasses are used on 14 and 1 percent of the plots respectively. Crop residues are often ploughed down and wild grasses are used to protect the seedbeds. We found that in areas where chemical fertilizers are less intensively applied (village of Kounakogou for instance), farmers often make more use of green manure, i.e. access to chemical fertilizers might be negatively correlated with the use of green manure (see table 2).

Fallowing and crop-rotation

In spite of increasing scarcity of the land, fallowing still remains for many farmers an option for improving soil fertility. However, the majority of the farmers (52%) has no land under fallow and for those who have a fallow, its duration hardly exceeds 3 years while the cultivation period often lasts more than 4 years. Consequently, the effects of the fallowing on yields is likely to be insignificant unless the other methods of fertilization are used. Boukombé's farmers appreciate much more the effect of the crop-rotation on the yields. Hungry rice is very appreciated as cover crop and it's often cultivated after or before high-demanding crops such as sorghum or maize. It is grown by 60% of the farmers of our sample and occupies the highest proportion of cultivated land (17%). Morphopedological studies in the area also report that soil loss are less on fields where hungry rice is cultivated (Azontonde, 1981, ORSTOM, 1961). It is worth noting that the hungry rice is also a very drought-resistant crop; it has a very developed root system and a relatively short vegetative period (2.5-3 months). This might also explain why it is widely cultivated. Nevertheless, the dynamics of the production patterns in the area (1964-1998) indicate that hungry rice is the only cereal whose area is experiencing a very fast decline; on the contrary, the area of maize, for instance, has been multiplied by twenty between 1969 and 1998 while the area of sorghum or millet remains stable. It is likely that the hungry rice is gradually dropped out from the production systems and replaced by maize on which chemical fertilizers are widely and heavily applied (in 1998/1999, an estimated average of 186 kg of fertilizers was applied per hectare on maize).

4. Empirical model for estimating return from indigenous soil and water conservation

Production function approach

We use a production function approach to analyze the productivity of SWC investments on farm output. We estimate a Cobb-Douglas production function relating farm output to farm inputs and other factors affecting productivity:

$$\ln(\text{output}) = \alpha_0 + \Sigma_i \alpha_i \ln X_i + \Sigma_j \alpha_j Z_j$$

where α_0, α_i , α_j are the coefficients, X_i are the inputs and Z_i are the other factors affecting productivity. The Cobb-Douglas is a special case of the translog production function, which also includes interaction terms among the right-hand side variables. The translog production is in principle more general and flexible than the special case of the Cobb Douglas production function, and we therefore also test whether the more general translog specification gives a better fit of the data.

Definition and summary statistics of regression variables

Table 3 gives the summary statistics for the model variables. **Output** is measured in kilograms. Only plots with cereals (sorghum, millet, maize, hungry rice) and cereals mixed with beans were included[9]. For the plots in the sample, the average output is about 200 kilograms. Given that the average plot size is approximately 0.60 hectares, the average output per hectare is 328 kg.[10] With respect to the inputs, **labor** is measured as the total amount of full labor days used for clearance, tillage, planting, weeding, harvesting, applying fertilizers and/or pesticides, and manuring and composting. Family labor, hired labor, and exchange labor is included. Labor is standardized into adults equivalents, where 1 is for adult men, 0.75 for adult women, and 0.25 for children. **Land** is given in hectares, and the plots are on average 0.60 hectares. The average plot receives about 54 full days of equivalent labor per cropping season. The amount of **fertilizer** is given in kilograms. On average farmers use approximately 10 kilograms of fertilizer.[11] We have also included the average number of **livestock** per plot because the manure functions as an input in the production system. The amount of livestock may also be a proxy for wealth. Wealth may affect production given that credit markets are imperfect and wealthy farmers may have better access to credit and less hesitant to use it. The total livestock is measured in Tropical Livestock Units (cow and oxen = 1.0, sheep and goats = 0.20), and amounts to 0.50 livestock unit per plot. The dummy variable **manure** equals one if farmers use manure and zero otherwise, and 7% of the plots use manure. This discrete variable is

[9] On average, more than 2/3 of the total cultivated land are planted with sorghum, millet, hungry rice, maize and beans per household.

[10] This is much lower than the average yields reported by CARDER, which is responsible for gathering data on farm output in Benin. Similar low yields have also been found for the Atacora (surveys UNB/VU 1995-1996, research project on 'Soil Degradation in Benin: Farmers' perceptions and rational behaviour' sponsored by the CREED) and for Southern Benin (surveys UNIHO-G5 1994-1998, research program on 'Participatory Technology Development for soil fertility restoration in Southern Benin' sponsored by the German Government). Unfortunately none of the CARDER reports explains the derivation of their published yields (see Gandonou and Adégbidi 2000).

sometimes used instead of the continuous livestock variable, because it varies by plot within the household.[12] On 9 percent of the plots farmers use **animal traction**, and it may be assumed that this affects production positively (although it may also increase erosion).

In terms of plot characteristics, the dummy variable **high plot fertility ranking** indicates whether the farmer ranks the fertility level of his plot among the top half of his plots. It may be assumed that plots of higher fertility are more productive. The dummy variables **rocky soil** and **gravelly soil** indicate whether the plot is on rocky, respectively gravelly soil. Sixty five percent of the plots have either rocky or gravelly soil, which should be less productive than the omitted category of sandy, loamy, and/or clayey soil. The dummy variables **light slope** and **steep slope** indicate whether the plot is respectively on a slope up till 10% or on a slope in excess of 10%. The steeper the slope, the more problems there will be with soil erosion and runoff, and the less productive the plot will be. In the sample 35% of the plots is on light slopes, and 17% of the plots is on steep slopes. The **distance to home** is measured in kilometers, and is 570 meters on average. Because farmers will try to avoid travel time and transportation costs, plots which are located further from the *tata* may receive less attention . The last plot characteristic we have included is the dummy variable **plot is borrowed/rented**. The effect of tenure on productivity is potentially negative -farmers may be less motivated to improve borrowed or rented plots. At the same time this tenure effect may be stronger if we examine the adoption of soil and water conservation investments as farmers will be able to reap the full benefit from any other, variable, inputs. On average 14% of the plots is borrowed or rented.

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[11] Fertilizer is applied to 15% of the plots included in the regression analysis.
[12] This is important if we want to control for household fixed effects.

With respect to indigenous soil and water conservation techniques we have included four dummy variables. The first is **stone bunds** and the table shows that 24% of the plots have these soil conservation structures. The second soil and water conservation dummy variable is for the presence of **tie-ridging (variant 1)** on the plot. This is the physical conservation technique which has been most frequently adopted (40%). The third soil and water conservation dummy variable is for the **other type of ridging (tie-ridging variant 2, perpendicular ridging, contour ploughing or contour bund)** which has been adopted on 9% of the plots. Here we have combined indigenous and non-indigenous techniques because they are very similar and each of them is used on very few plots. The last variable is for the presence of a **water catchment** on the plot -only 2% of the plots have this type of physical structure. It is assumed that each of these techniques has a positive impact on productivity.

For household characteristics we include the **number of plots**. If farms are very fragmented, farmers will be less able to take advantage of possible economies of scale at the plot-level (such as ploughing, manuring). We also include in the regressions village dummies to control for other, not included, village differences, such as differences in overall soil fertility, differences in knowledge and farming tradition, the access to exchange labor, and distance to markets.

5. Empirical results

Bivariate analysis of yields and use of soil conservation techniques

First we present a number of cross tables which give the mean plot yield by adoption of soil conservation technique for each of the villages. Next we will apply multivariate regression techniques to estimate an agricultural production function for plot output taking into account inputs, plot characteristics, adoption of soil and water conservation techniques, household and village characteristics. Plot output is measured as the total number of kilogram per plot, and plot yields are measured as plot output per ha. We have only included plots on which the following cereals were grown: sorghum, millet, maize, hungry rice. We have also included plots for which these cereals were grown as well as beans because many plots have a mixture of millet or sorghum with (some) beans.

Table 4 reports the difference in yields between plots with and without indigenous soil and water conservation techniques. On average for all villages (last column), we see that plots with tie-ridging, variant 1 (‘*billonnage cloisonné*’), water catchment, fertilizer and manure do better than plots without these conservation structures. No clear effect if found for other type of ridging, and actually plots with stone bunds do *worse* than plots without these conservation structures. There are differences between the villages, however, such that in some villages plots with a technique are more productive and in others less productive than plots without the technique.

The most likely explanation for this ambiguity is that there are differences in plot characteristics between plots with and without the soil and water conservation technique. In particular, plots which suffer from erosion, lack of water retention or low fertility in the first place, may be more likely to receive soil and water conservation investments than plots which have no such problems. In these instances farmers will be more motivated to try to improve these plots. Still, the table suggests that soil and water conservation techniques are productive as we observe higher productivity for most of the indigenous soil and water conservation techniques.

Multivariate regression analysis

The above bivariate tables suggest that there are productivity effects from soil conservation in the region of Boukombé in the north-west of Benin. Plots which have tie-ridging, water catchments, fertilizer or manure show higher yields on average. Plots with stone bunds and other types of ridging, however, do not show higher yields than plots without these measures. The interesting question becomes therefore whether we can find productivity effects if we would control for other, possibly intervening factors. Plots which are steeper might receive more soil conservation investments, although they are less productive than plots with less slope. Farmers might choose to invest in fields which lack organic matter or minerals.

Ordinary least squares versus household fixed effects regression

The first two columns of table 5 report the regression results if we use ordinary least squares (OLS) to estimate the Cobb-Douglas production function. Significant positive effects on physical cereal output are produced by labor, land, the amount of fertilizer, number of livestock, and the presence of a water catchment. The use of animal traction appears to have a positive effect, although the effect is has p-value of 0.15 possibly because of multicollinearity with the village dummy for Okouaro as all plots receiving animal traction are located in this village (correlation coefficient is 0.49). There is a significant negative effect on production if the plot is on a steep slope and plots on light slope appear also to be less productive.

From the OLS regression one could conclude that the soil and water conservation investments are not productive except for water catchments. We checked for the robustness of this result by estimating the production function by quantile regression as well. The coefficients do barely change, which suggests that the result is not due to outliers or big tails. We have also tested whether the Cobb-Douglas specification needs to be rejected in favor of the more flexible and general translog specification. In particular, we have included square terms for the land and labor variables, and interaction terms for land and labor with each other and with the soil and water conservation investments. This test on the validity of the Cobb-Douglas specification has a p-value of 0.93, and the Cobb-Douglas specification is therefore not rejected.

The fact that most of the coefficients for the SWC investments are negative suggests another interpretation, namely that the presence of these investments become a proxy for relatively infertile and/or eroded soils. Our fertility ranking variable captures differences in fertility across plots for a given household, but not for differences in average plot fertility across households. Other household-level factors may also have been omitted, such as farming skills, labor and credit constraints.

In order to control for these differences, we exploit the fact that we have multiple plot-level observations for each household. Hence, we can control for household-level differences by including dummies for each household in the model. In the last two columns of table 5 the results are reported for a household fixed effects regression. The effects for labor, land, and amount of fertilizer are surprisingly robust and remain highly significant. Instead of the amount of livestock we have included a dummy for the use of manure, because this measure is available at the plot-level. The effect of manuring is no longer found to be significant however.

Plots on gravelly soil are now found to be less productive, and the coefficient for rocky soil is also (as expected) negative. Most importantly, however, the sign on the soil conservation techniques are now all positive, but only the effect from water catchments is found to be significantly so.

The test on the validity of the Cobb-Douglas specification has a p-value of 0.21, and the Cobb-Douglas specification is therefore not rejected against the more general translog specification.

Interaction effects with indigenous SWC techniques

The above result suggests that soil conservation may be productive but the results suffer from a lack of significance. The results may suffer from a misspecification bias, however. In the above specification, the effect of soil conservation is assumed to be the same for all villages. This might not be the case however, as there are village differences in terms of average plot fertility, slope level, expertise, motivation and tradition in regard of soil conservation. We might expect, therefore, that the productivity of soil conservation techniques may vary across villages, and therefore that interaction terms between the SWC dummies and village dummies need to be included.[13] Using F-tests to test for this possibility, there are no significant differences in productivity for the conservation techniques except with respect to the tie-ridging. In particular, the productivity of tie-ridging appears to be significantly higher in the villages Takouanta or Kounakogou compared to the villages Okouaro or Koutagou. The p-values for the tests of no village differences in productivity of SWC techniques are 0.13 for stone bunds, 0.04 for tie-ridging variant 1, and 0.70 for other types of ridging. The F-test for equal productivity of tie-riding (variant 1) is 0.93 for the villages Takouanta and Kounakogou and 0.50 for the villages Okouaro and Koutagou. These tests are supported from what has been observed during the many field visits to these villages. The skills of farmers in

[13] The same might be said for differences in productivity across households (or even plots). We are not able to test for such differences however because the inclusion of household-specific soil conservation dummy variables is not feasible because farmers have too few plots. In table 12 we will investigate whether specific plot characteristics (there: slope type) can capture some of these household and plot-

Takouanta and Kounakogou in constructing soil conservation measures are highly developed, either because of need (Takouanta) or because of outside intervention (Kounakogou has been involved in projects undertaken by the extension service CARDER and the World bank).

The next regression (first two columns of table 6) shows the results if we control for these village differences. The coefficients for labor, land, and amount of fertilizer remain strongly significant. Now the plot fertility ranking becomes significant as well, although the soil type dummies loose significance (but retain the correct signs). Interestingly, the effect of soil conservation on productivity becomes very clear now with stone bunds, tie-ridging, other type of ridging and water catchment all having positive and significant signs. Only the productivity effect of tie-ridging for Okouaro or Koutagou cannot be found. The coefficients for stone bunds, tie-ridging, other ridging are surprisingly close and quite large, suggesting productivity effects in excess of 90%.[14]

Besides interaction terms between indigenous techniques and village dummies, it may also be expected that other kinds of interaction terms with the SWC techniques may be relevant. We have pursued three possibilities, namely that the productivity of stone bunds is higher (1) if they are perpendicular with regards to the slope, (2) if they are reported to be of good quality (as opposed to poor quality), and (3) if they are used in combination with fertilizer. The role of the last interaction effect with fertilizer is also investigated for the two tie-ridging techniques.

We do not find that perpendicular or good quality stone bunds are more productive (the p-values are 0.98 and 0.42 respectively). Possibly the productivity

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level differences in the productivity of soil conservation.

[14] The effect of a dummy variable in a loglinear model is given by $\exp(\alpha)-1$.

differences are too small here to be picked up by our relatively small sample. The effect of the indigenous techniques depends strongly on the use of fertilizer, however. In the last two columns we report the regression results if we include an interaction term between the stone bund dummy and the fertilizer variable. The results show that there is a strong interaction effect between the use of fertilizer and the presence of stone bunds. This is intuitive, as the presence of stone bunds will make it more likely that fertilizer will not be washed or blown away. We also have tested whether tie-ridging in combination with fertilizer becomes more productive, but we find no significant effect, probably because they are less successful in retaining fertilizer.[15]

Once again we have tested whether the Cobb-Douglas specification needs to be rejected in favor of the more flexible and general translog specification. After including square terms for the land and labor variables, and interaction terms for land and labor with each other and with the soil and water conservation investments, the test on the validity of the Cobb-Douglas specification has only a p-value of respectively 0.28 and 0.26 for the regressions reported in table 6

Plot level differences in productivity of indigenous SWC techniques

The results in table 6 show that soil conservation investments have been effective in the research villages of Boukombé. However, the effects measured are <u>average</u> effects of soil conservation on productivity across plots. This average effect will be very different from the <u>marginal</u> effect of adopting soil conservation measures on any given plot. If farmers choose to invest first in the plots where the benefits of soil conservation are the highest, then the productivity of soil conservation investment is falling with increasing investment. Hence, if we want to answer the question

[15] The p-value of the test is only 0.91. We did not test for the presence of an interaction term with the water catchment dummy because very few plots have water catchments.

whether more or less conservation investment is needed in a given village, we need to know the effect of soil conservation at the plot-level.[16]

The effect of soil conservation at the plot-level will depend on soil type (erodibility of soil), cropping pattern, rainfall and runoff, and soil conservation investments already undertaken on the plot. There are two ways to measure the productivity of soil conservation at the plot-level. On the one hand one could include interaction terms of soil conservation measures with plot characteristics (soil type, cropping pattern, earlier investments made). On the other hand, one could follow the procedure followed by Byiringiro and Reardon (1996), and calculate an index of erosion for each plot which depends on plot characteristics, cropping pattern, and rainfall (using the Universal Soil Loss Equation). This latter approach has the advantage that it avoids the need to include many interaction terms in the regression (with the risk of overfitting the data). It also allows to control for rainfall even if we have rainfall measures which are the same for all farmers. A major drawback, however, is that there is no calibrated version of the USLE available for the Boukombé region and that the results depend on the quality of the USLE calibration. Therefore, we have estimated the productivity effect of soil conservation for different slope types (see table 7).

The table shows that the productivity of stone bunds, tie-ridging, other ridging is plot-dependent and depends on the slope of the plot; the productivity is first increasing in slope and then decreasing. [17] The highest productivity is found for plots

[16] Also at the plot-level there will be a difference between average and marginal effect. This difference will be ignored, however, given that the difference between average and marginal effect will be much smaller at the plot-level than at the village-level. This is because the intra-plot variation is much smaller than the between-plot variation of plot characteristics (such as fertility and slope).

[17] No interaction terms were included for tie-ridging in Okouaro or Koutagou because they turned out to be insignificant as well. No interaction terms were included for water catchments because they are found on only few plots.

with intermediate, that is lightly sloped plots. They appear least effective on steep plots. The other type of ridging appears to loose all effectiveness on steep plots. The use of fertilizer only improves the productivity of stone bunds on flat and light slopes. This is intuitive, given that on steep slopes even stone bunds will have difficulty retaining the applied fertilizer.

We now discuss whether the above results may have been biased because of endogeneity, omitted variable or sample selectivity bias. We discuss each of these misspecification problems in turn.

Endogeneity bias

One may argue that the above results may be biased because of endogeneity bias. The use of labor and fertilizer may be endogenous, as farmers may increase the input of labor and fertilizer during the season if they observe that plot output is lower than expected. Labor input will also be affected by plot output as it includes harvesting labor. We have tested whether the above results suffer from endogeneity bias in the labor and fertilizer variable. We have re-estimated the last regression in table 7 to control for possible endogeneity of the labor and fertilizer variable. We have used as instruments the average labor and fertilizer use on the other plots of the farm and the average soil type of the other plots.[18] The interaction terms between stone bunds, slope type and fertilizer use were instrumented with interaction terms between stone bunds, slope type and average fertilizer use on the other plots. It may be argued that labor and fertilizer use on the different plots of a farm are correlated through the budget and time constraints, and therefore not valid instruments. However, the correlation between the average labor and fertilizer use on other plots

[18] The average soil type of the other plots is measured by the average values of the dummy variables for rocky and gravelly soil across the other plots.

and the disturbance term should be very weak given that on average farm households cultivate more than 6 plots and given that there are soft resource constraints for fertilizer and labor use.[19] Also there are no other obvious instruments available which are plot-specific.[20] Hence we will use these variables as instruments, but we will formally test whether they can be accepted as valid instruments (see further).

The Hausman χ^2-test for the null hypothesis that there is no endogeneity bias equals only 0.09 and is therefore not significant at 10% (26 degrees of freedom). From this, we may conclude that the above results do not suffer from endogeneity bias in the labor and fertilizer variables. Before concluding this, however, we need to check the quality of the instruments used. First, Bound et al. (1993) and Staiger et al. (1994) have noted that if instruments are very weakly correlated with the endogenous variables, even a very small correlation between the instrument and the disturbance term will produce a larger inconsistency in the instrumental regression estimates than in the non-instrumented regression estimates. Second, in finite samples, instrumental estimates are biased in the same direction as OLS estimates. Bound et al. suggest that to gauge the severity of both problems that both the partial R^2 and the F-statistic on the excluded instruments from the first stage estimation be reported when using instrumental regression as approximate guides to the quality of the instrumental estimates. In our case these checks suggests that there is no problem. The partial R^2 of labor and fertilizer use on the instruments are 0.05 and 0.04 respectively, which are

[19] Suppose household h allocates T units of farm labor across N plots: $(N-1)\overline{L}_{hp} + L_{hp} = T$, where $\overline{L}_{hp}$ indicates the average labor use on other plots than plot p, and L_{hp} the labor use on plot p. Hence for given resources T, $\Delta\overline{L}_{hp} = \frac{1}{N-1}\Delta L_{hp}$, and the correlation of $\overline{L}_{hp}$ with the plot-specific disturbance term ε_{hp} will be smaller as N grows larger. Also, the correlation will be even weaker if there is a soft resource constraint for labor and fertilizer use, as households will increase total labor and fertilizer use to accommodate any plot-specific productivity shocks. This implies that labor and fertilizer use on the other plots will fall even less with any increase in labor and fertilizer use on a given plot.

[20] An obvious instrument for the use of fertilizer is the availability of migrant remittances in the

relatively large, and the F-statistic on the excluded instruments in the first stage estimation are 2.79 and 1.97 for labor and fertilizer use respectively.[21]

Besides the quality of the instruments it has also been argued that one should check the validity of the instruments, by testing whether the instruments do not affect plot output directly (exclusion restrictions). To test whether our instruments have any direct influence on earnings we have undertaken a test of overidentifying restrictions (Sargan test) on the instrument set used. The test on overidentifying restrictions is not rejected (p-value 0.29), and our instruments are therefore validated.

Omitted variable bias

One may argue that our results suffer from an omitted variable bias because we do not control for unobserved plot characteristics. In principle this should be a concern indeed, as we do not have a panel data set and we are therefore unable to include plot fixed effects to control for such unobservables. To control for plot characteristics, we have included a number of plot characteristics to mitigate this problem, namely the fertility level, soil type, and slope type of the plot. However, if these observed plot characteristics do not fully control for unobservable differences in plot quality, our estimates of the productivity of indigenous techniques may be biased if there is a correlation between these techniques and the quality of the plot. For instance, if indigenous techniques are more likely to be used on high quality plots, then the observed productivity effect of these techniques may reflect underlying plot quality differences rather than productivity effects. In order to explore this possibility, we have tested whether the productivity of indigenous techniques is different for plots

household. We cannot use this as instrument however because the instruments need to be plot-specific with the inclusion of household fixed effects.

[21] Bound et al. suggest that "an F-statistic at all close to one should be cause for concern".

which have been reported to be relatively fertile compared to plots which have been reported to be less fertile.[22] Because we distinguish between productivity effects at different levels of fertility, the estimated productivity effects should be less affected by any correlation between techniques and plot quality. We do not find any differences in productivity of indigenous techniques between fertile and less fertile plots, and the observed productivity effects are very similar to those observed before.[23] This suggests that the observed productivity effects of indigenous techniques are not driven by omitted variable bias.

Sample selectivity bias

We have estimated the productivity of indigenous techniques only for plots on which cereals are grown, and therefore we may have introduced a sample selectivity bias. If fields with indigenous techniques are more likely to be used for cereals, we may have induced a correlation between the disturbance term and the dummies for indigenous techniques (see Greene, section 20.4). In order to control for this type of sample selectivity bias, we use a methodology derived in Dubin and McFadden (1984). This requires the estimation of a reduced form multinomial logit model of crop choice, from which a set of Dubin-McFadden selection correction terms are constructed (predicted) for each plot. The predicted correction terms are included as regressors in the production function regression. The results for the crop choice model are reported in the appendix. We distinguish between three crop choices, namely (1) cereals (possibly mixed with beans), (2) other crops, and (3) fallow. The results show that there are significant correlations between the use of indigenous techniques and

[22] We assume that plot quality is correlated with (but not fully captured by) reported fertility levels. Technically, we have included interaction terms for the indigenous techniques and the dummy for high plot fertility ranking.
[23] Results are available from the authors on request.

crop choice, and generally the presence of indigenous techniques seems to favor cereals (almost all coefficients of the indigenous techniques are negative for other crops and fallow). Using these estimates, we include the constructed Dubin-McFadden selection correction terms in the production function regression. We add the selection terms to the first regression reported in table 7 (last two columns).

We note that the selection terms are not significant and therefore we cannot reject the hypothesis that there is no sample selectivity problem.[24] The signs on the selectivity terms are intuitive, however, implying a positive correlation between the choice for other crops and cereal productivity and a negative correlation between the choice for fallow and cereal productivity. Also, we observe that a number of coefficients are strongly affected by the inclusion of the selection terms. This suggests that selectivity *may* be a problem but that our sample size is too small to reject the absence of sample selectivity. Looking at the productivity of indigenous techniques, we see that the results for tie-ridging are most affected, with no longer a significant effect from tie-ridging in Takouanta or Kounakogou, and a significantly *negative* effect for Okouaro or Koutagou. For other type of tie-ridging, though, we find an even stronger productivity effect. Plots with tie-ridging are far more likely to be used for cereals, and the sample selectivity terms may correct for the induced correlation between the disturbance term and tie-ridging dummies.

6. Conclusions and discussion

In this paper we have tried to examine the productivity of soil conservation techniques as adopted in Boukombé. Farmers have adopted a wide range of conservation techniques, but they have also often abandoned earlier adopted

[24] The p-value for the joint test that both selection terms are not different from zero is 0.11.

techniques, presumably because they were not as productive as anticipated. If we can observe how much farmers do benefit from these techniques within the actual context of Boukombé, then it will be possible to assess what the productivity benefit will be of additional soil conservation investments.

The results show that there are clear productivity effects if one controls for household fixed effects. Productivity is also shown to depend on plot characteristics, particularly slope type. If a calibrated version of the USLE can be found for the Boukombé region, then it will be possible to further disaggregate the productivity effect along differences in soil type, cropping pattern, rainfall, and other investments made. This is planned as a next step of research.

Still, even if it can be established that there are cost-effective ways to improve productivity, it will be important to assess how certain these benefits will be at the farm-level. Even if average productivity gains can be expected to be very high, individual farmers may abstain from investments if the productivity benefits are uncertain and investment is (partially) irreversible. This will be especially the case for investments in physical conservation structures, and the potential welfare loss from too low investment could be large in light of the strong productivity effects observed for these investments.

Another issue is whether the observed productivity effects are atypical, in the sense that the survey period was atypical. Rainfall during the 1998-99 season was 1470 mm which is 36% higher than the average annual rainfall in the last 76 years. During the planting period (May-June) the total rainfall was also very high (62% higher than the average). Similar figures are also observed for the rainfall intensity (113 mm/day versus an average of 83mm/day for the whole year; 21 mm/day versus an average of 13 mm/day during the planting period). If productivity effects depend on rainfall, they may have been atypical as well. However, it is difficult to assess whether the observed productivity effects are an over or underestimate of the average productivity effects. Although many farmers in our study area considered heavy rains as having negative effects on productivity in spite of the very wide application of various mechanical and non mechanical conservation structures, it may well be possible that without those structures they would have been even worse off. Longitudinal data on soil and water conservation investments in combination with production and rainfall data should shed more light on this issue.

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Table 1: Household characteristics, economic activities and income in the sub-prefecture of Boukombé (Northwest Bénin)

		Takouanta (N=25)	Koutagou (N=25)	Kounakogou (N=26)	Okouaro (N=25)	All villages (N=101)
Assets						
	Quality of the land at the village level[a]	very low	low	low to medium	medium to good	-
	Average farm size (in hectares)	4.13	2.00	2.70	4.36	3.29
	Average area cultivated (in hectares)	1.68	1.30	2.47	3.37	2.21
	Average number of goats and sheep, mean of the non-zero reported values[b]	5 (52%)	5 (68%)	6 (88%)	6 (76%)	5 (71%)
	Average number of cattle, mean of the non-zero reported values [b]	4 (28%)	4 (48%)	4 (42%)	5 (44%)	4 (41%)
	Ownership of ox-plough (% of households)	0	0	0	28	7
Household population						
	Average household size	5	7	6	7	6
	Active population, 15-59 year (%)	57	52	51	43	
	Average age of the household head (year)	49	47	47	44	46
Gross annual farm output [c] in fcfa [d], sample mean		69,542	97,425	106,485	173,546	111,700
Other sources of income (percentage of households engaged)						
	Sales of animal products (chicken, guinea fowl, eggs, honey, sheep, goat, pig, duck, etc.)	16	60	50	24	38
	(Distress) sales of cattle	0	8	0	4	3
	Sales of gathering products and fruits[e]	48	4	100	0	39
	Non-farm self-employment [f]	24	28	27	16	24
	Temporary migration [g]	0	4	0	12	4
	Wage labor employment	12	4	0	0	4
Migration						
	Incidence of migration (% of households with at least one migrant)	16	72	16	4	28
	Remittances (fcfa), mean of the non-zero reported values	22,500	46,433	46,800	0	42,520
Connection to roads and markets		bad	medium to good	medium	good	-

[a] This is compared to the average quality of the land at the level of the whole sub-prefecture of Boukombé.

[b] In the brackets are indicated the percentage of households which own at least one animal.

[c] We include only the main food crops and the commercial crops grown in the study area (sorghum, hungry rice, millet, maize, rice, bean, groundnut, bambara groundnut, yam, cotton, tobacco). The value of the output is imputed by using the sample median of the selling prices which have been reported by the surveyed households. The percentage of households which have reported some sales of food crops during the year of the study are as follows : sorghum (28% of growers), hungy rice (34%), millet (3%), maize (22%), rice (39%), bean (29%), bambara groundnut (12%), yam (9%). The food crops whose production are not included in the total annual gross output are: gumbo, pepper, sweet potatoes, tomatoes and cassava; most of them are cultivated by a negligible number of households (1%); the only exception is gumbo which is grown by 7% of the household but it often occupies a negligible portion of the cultivated land. Note, also, that reliable price figures are not available for these crops in the study area.

[d] US$1 = FCFA 738.23

[e] These include firewood, fruits of wild trees such as shea (*Vitellaria paradoxa*), baobab (*Adansonia digitata*), *Parkia Biglobosa* as well as fruits of planted trees like cashew and mango trees.

[f] These include small-scale processing activities (production of the very popular traditional beer called*tchoukoutou* made of sorghum, production of shea butter, etc.), small-scale trade and handicrafts (mainly pottery). Female household members are the most employed in these activities.

[g] Mainly young household members (aged between 17-25 years) are engaged in these activities. They leave the household as soon as the hardest on-farm works have been completed (often after the weeding activities) to seek a temporary farm employment in the most important cotton growing areas of Benin (e.g. in the provinces of Borgou in the North-east, and Zou in the centre of Benin); sometimes, they travel to the neighboring countries (Ghana, Togo, Nigeria) where they are also employed mainly in the farm sector.

Source : Survey UNB/VU (1999)

Table 2: Rate and intensity of adoption of the soil and water conservation techniques in Boukombé.

		Takouanta	Okouaro	Kounakogou	Koutagou	All villages
Indigenous Techniques						
Stone bunds	% households	96	0	8	84	47
	% plots	59	0	2	55	23
	% land	69	0	2	62	23
Tie-ridging 1	% households	52	36	92	48	57
	% plots	33	14	72	27	34
	% land	24	16	68	19	33
Tie-ridging 2	% households	4	4	50	4	16
	% plots	1	1	19	2	5
	% land	1	1	24	3	8
Water catchments	% households	28	0	27	44	25
	% plots	11	0	15	18	9
	% land	9	0	9	19	7
Animal manure	% households	16	24	4	12	14
	% plots	5	5	1	5	4
	% land	3	4	1	2	3
Green manure	% households	24	20	46	4	24
	% plots	13	6	40	1	14
	% land	14	10	42	0	19
Mulching	% households	0	12	0	0	3
	% plots	0	3	0	0	1
	% land	0	5	0	0	2
Fallowing	% households	80	32	19	64	48
	% plots	38	5	5	20	17
	% land	58	19	9	35	31
Crop-rotation	% households	32	38	62	80	60
(cultivation of hungry	% plots	9	11	16	26	15
rice)	% land	10	10	20	40	17
Non-Indigenous Techniques						
Tree planting	% household					
	no planted trees	48	60	54	52	54
	1-5 trees	16	16	35	40	27
	> 5 trees	36	24	12	8	20
Live barrier, vetiver	% households	0	0	4	0	1
	% plots	0	0	2	0	1
	% land	0	0	2	0	1
Fertilizers	% households	32	36	27	44	35
	% plots	10	11	10	18	12
	% land	8	11	12	22	12
Compost	% households	4	20	12	0	9
	% plots	1	3	9	0	4
	% land	1	3	7	0	3
Contour bunds	% households	0	0	23	2	8
(banquettes)	% plots	0	0	8	4	3
	% land	0	0	8	3	3
Contour ploughing	% households	0	0	4	4	2
	% plots	0	0	1	3	1
	% land	0	0	1	2	1

Table 3. Descriptive statistics of model variables.

Variable	Obs	Mean	Std.Dev.	Min	Max
output (kg)	246	197.98	149.56	10.00	800.00
Inputs					
labor (equivalent labor)	246	54.23	31.02	4.50	205.94
land (ha)	246	0.60	0.49	0.13	4.00
amount of fertilizer (kg)	246	9.53	25.75	0.00	150.00
number of livestock (TLU)	246	0.53	0.64	0.00	5.33
use of manure	246	0.07	0.25	0.00	1.00
use of animal traction (dummy)	246	0.09	0.28	0.00	1.00
Plot characteristics					
high plot fertility ranking (dummy)	246	0.46	0.50	0.00	1.00
rocky soil (dummy)	246	0.21	0.41	0.00	1.00
gravelly soil (dummy)	246	0.44	0.50	0.00	1.00
light slope (dummy)	246	0.35	0.48	0.00	1.00
steep slope (dummy)	246	0.17	0.38	0.00	1.00
distance to home (km)	246	0.57	0.88	0.00	5.00
plot is borrowed/rented (dummy)	246	0.14	0.35	0.00	1.00
Soil and water conservation					
Stone bunds (dummy)	246	0.24	0.43	0.00	1.00
Tie-ridging (dummy)	246	0.40	0.49	0.00	1.00
Other type of ridging (dummy)	246	0.09	0.29	0.00	1.00
Water catchment (dummy)	246	0.02	0.14	0.00	1.00
Household characteristics					
number of plots	246	6.20	3.17	1.00	17.00
Village fixed effects					
Takouanta (dummy)	246	0.25	0.43	0.00	1.00
Okouaro (dummy)	246	0.30	0.46	0.00	1.00
Kounakogou (dummy)	246	0.30	0.46	0.00	1.00

Table 4: Adoption of indigenous techniques and average plot yield (kg/ha). Number of plots within brackets

Technique	Takouanta		Okouaro		Kounakogou		Koutagou		All villages	
stonebunds										
yes	**301**	(39)			**267**	(2)	**625**	(19)	**403**	(60)
no	**472**	(22)	**397**	(79)	**442**	(71)	**544**	(21)	**438**	(193)
tie-ridging, variant 1										
yes	**480**	(21)	**306**	(12)	**440**	(57)	**629**	(9)	**450**	(99)
no	**301**	(40)	**413**	(67)	**426**	(16)	**569**	(31)	**417**	(154)
other type of ridging										
yes			**125**	(1)	**452**	(15)	**422**	(6)	**429**	(22)
no	**363**	(61)	**400**	(78)	**433**	(58)	**611**	(34)	**430**	(231)
water catchment										
yes					**700**	(2)	**1106**	(3)	**943**	(5)
no	**363**	(61)	**397**	(79)	**430**	(71)	**540**	(37)	**419**	(248)
fertilizer										
yes	**638**	(8)	**612**	(17)	**780**	(5)	**489**	(8)	**614**	(38)
no	**321**	(53)	**338**	(62)	**412**	(68)	**606**	(32)	**397**	(215)
manure										
yes	**380**	(4)	**414**	(8)	**480**	(5)	**1600**	(1)	**491**	(18)
no	**361**	(57)	**395**	(71)	**434**	(68)	**557**	(39)	**425**	(235)

Table 5: Cobb-Douglas Production Function Estimates. Dependent variable is ln(output). OLS and Household Fixed Effects Regressions.

Variables	OLS		Fixed Effects	
	coefficient	t-value	coefficient	t-value
Variable inputs and medium-term land investments				
ln(labor) (equivalent labor)	**0.27**	2.87	**0.36**	3.13
ln(land) (ha)	**0.37**	5.33	**0.30**	3.00
amount of fertilizer (kg)	**0.004**	2.92	**0.004**	2.34
number of livestock (TLU)	**0.15**	2.58	-0.16	-0.83
use of animal traction (dummy)	0.27	1.46	0.23	1.14
Plot characteristics				
high plot fertility ranking (dummy)	0.07	0.79	0.10	1.05
rocky soil (dummy)	0.12	0.75	-0.22	-0.92
gravelly soil (dummy)	0.10	0.82	**-0.26**	-1.66
light slope (dummy)	-0.15	-1.33	0.03	0.20
steep slope (dummy)	**-0.34**	-2.30	-0.13	-0.67
distance to home (km)	-0.02	-0.41	-0.02	-0.32
plot is borrowed/rented (dummy)	0.05	0.36	-0.13	-0.61
Soil and water conservation techniques				
Stone bunds (dummy)	-0.08	-0.40	0.25	0.95
Tie-ridging (dummy)	-0.12	-0.77	0.16	0.76
other type of ridging (dummy)	-0.09	-0.45	0.24	0.91
Water catchment (dummy)	**0.49**	1.67	**1.01**	2.78
Household characteristics				
number of plots	0.02	1.12		
Village fixed effects				
Takouanta (dummy)	**-0.60**	-4.03		
Okouaro (dummy)	**-0.52**	-2.73		
Kounakogou (dummy)	**-0.28**	-2.00		
Household fixed effects	no		yes	
constant	**4.43**	9.66	**3.79**	7.20
Number of observations	246		246	
R^2	0.35		0.22	
Significance household fixed effects (p-value)			0.0000	
Significance level regression (p-value)	0.0000		0.0001	

Standard errors are robust. Coefficients with p-value of 0.10 or less are printed in bold.

Table 6. Cobb-Douglas Production Function Estimates. Dependent variable is ln(output). Household fixed effects regressions. Including interaction terms with SWC investments.

Variables	coefficient	t-value	coefficient	t-value
Variable inputs and medium-term land investments				
ln(labor) (equivalent labor)	**0.34**	2.95	**0.34**	3.01
ln(land) (ha)	**0.29**	2.94	**0.31**	3.20
amount of fertilizer (kg)	**0.004**	2.12	0.002	0.78
use of manure (dummy)	-0.14	-0.73	-0.16	-0.87
use of animal traction (dummy)	0.20	1.04	0.30	1.58
Plot characteristics				
high plot fertility ranking (dummy)	**0.15**	1.63	**0.18**	1.94
rocky soil (dummy)	-0.13	-0.54	-0.14	-0.60
gravelly soil (dummy)	-0.20	-1.24	-0.22	-1.42
light slope (dummy)	0.02	0.17	0.02	0.12
steep slope (dummy)	-0.21	-1.09	-0.15	-0.80
distance to home (km)	-0.03	-0.50	-0.03	-0.47
plot is borrowed/rented (dummy)	-0.14	-0.68	-0.16	-0.80
Soil and water conservation techniques				
Stone bunds (dummy)	**0.65**	2.18	0.46	1.53
* amount of fertilizer (kg)			**0.01**	2.84
Tie-ridging (dummy)				
in Takouanta or Kounakogou	**0.72**	2.43	**0.66**	2.28
in Okouaro or Koutagou	-0.23	-0.91	-0.29	-1.18
Other type of ridging (dummy)	**0.70**	2.18	**0.61**	1.94
Water catchment (dummy)	**1.20**	3.30	**1.18**	3.34
Constant	**3.54**	6.77	**3.64**	7.11
Number of observations	246		246	
R^2 within	0.32		0.36	
R^2 between	0.08		0.09	
Significance level regression	0.0000		0.0000	

Standard errors are robust. Coefficients with p-value of 0.10 or less are printed in bold.

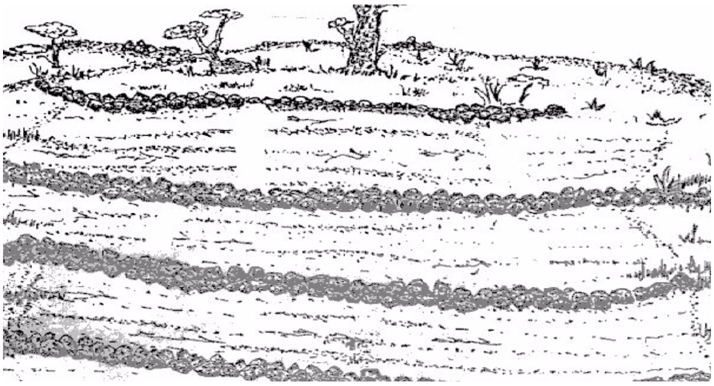
Table 7. Cobb-Douglas Production Function Estimates. Dependent variable is ln(output). Household fixed effects regression. Soil conservation productivity by slope type and with sample selectivity selection terms.

Variables	coefficient	t-value	coefficient	t-value
Inputs				
ln(labor) (equivalent labor)	**0.35**	3.03	**0.31**	2.63
ln(land) (ha)	**0.30**	3.03	**0.31**	3.15
amount of fertilizer (kg)	0.002	0.92	0.002	1.11
use of manure (dummy)	-0.13	-0.67	-0.03	-0.14
use of animal traction (dummy)	0.29	1.46	0.24	1.22
Plot characteristics				
high plot fertility ranking (dummy)	**0.17**	1.79	-0.33	-1.28
rocky soil (dummy)	-0.17	-0.68	**-0.86**	-1.92
gravelly soil (dummy)	-0.23	-1.40	**-0.79**	-2.32
light slope (dummy)	-0.11	-0.52	**-0.48**	-1.63
steep slope (dummy)	0.07	0.16	-0.67	-1.09
distance to home (km)	-0.02	-0.41	**0.23**	1.74
plot is borrowed/rented (dummy)	-0.20	-0.88	-0.19	-0.86
Soil and water conservation techniques				
Stone bunds (dummy)				
on flat slope	0.36	0.87	-0.11	-0.21
on light slope	**0.62**	1.63	0.13	0.30
on steep slope	0.35	0.65	0.16	0.28
* amount of fertilizer (kg)				
on flat slope	**0.01**	2.11	**0.01**	2.07
on light slope	**0.01**	2.13	**0.01**	1.93
on steep slope	0.00	0.16	-0.01	-0.28
Tie-ridging (dummy)				
in Takouanta or Kounakogou				
on flat slope	**0.66**	2.02	0.08	0.19
on light slope	**0.86**	2.24	0.30	0.65
on steep slope	0.51	0.88	0.27	0.46
in Okouaro or Koutagou	-0.26	-0.99	**-1.13**	-2.12
Other type of ridging (dummy)				
on flat slope	0.59	1.35	**1.66**	2.30
on light slope	**1.00**	2.52	**1.75**	2.98
on steep slope	0.02	0.04	0.97	1.22
Water catchment (dummy)	**1.15**	3.15	**1.10**	3.05
Constant	**3.56**	6.56	**6.08**	4.32
Sample selectivity selection terms				
Other crops selection term			1.56	1.57
Fallow selection term			-0.71	-1.12
Number of observations	246		246	
R^2 within	0.38		0.40	
R^2 between	0.08		0.01	
Significance level regression	0.0000		0.0000	

Coefficients with p-value of 0.10 or less are printed in bold.

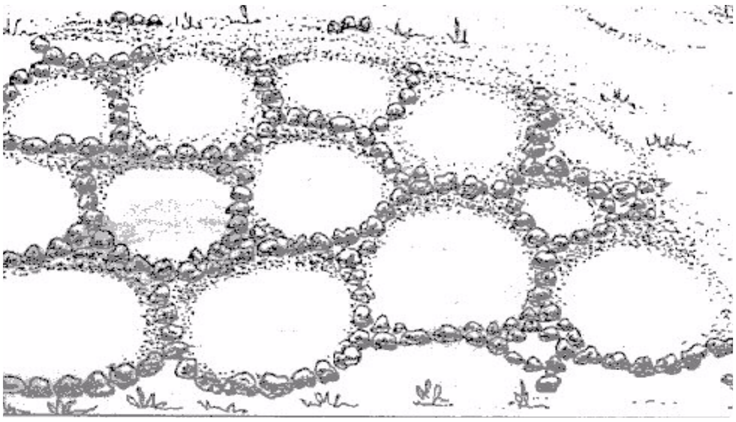
Appendix A.

Figure A.1: Stone bunds, variant 1



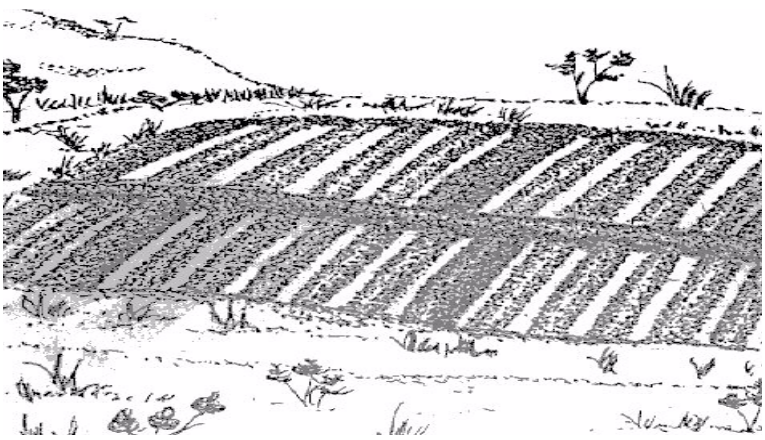
Source: Projet de Gestion des Ressources Naturelles

Figure A.2 : Stone bund, variant 2



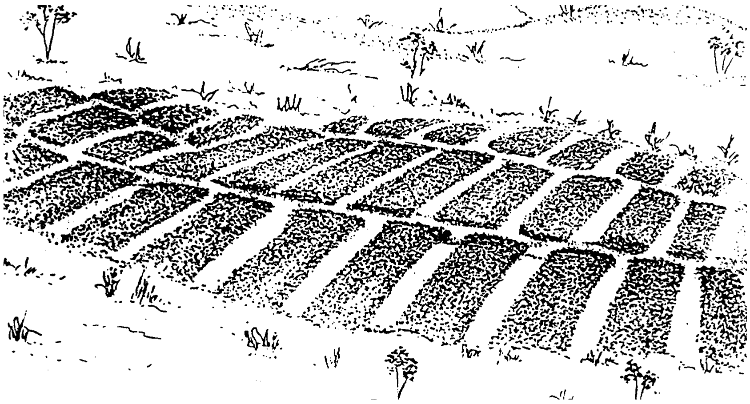
Source: Projet de Gestion des Ressources Naturelles

Figure A.3: Tie-ridging, variant 1 ('billonnage cloisonné')



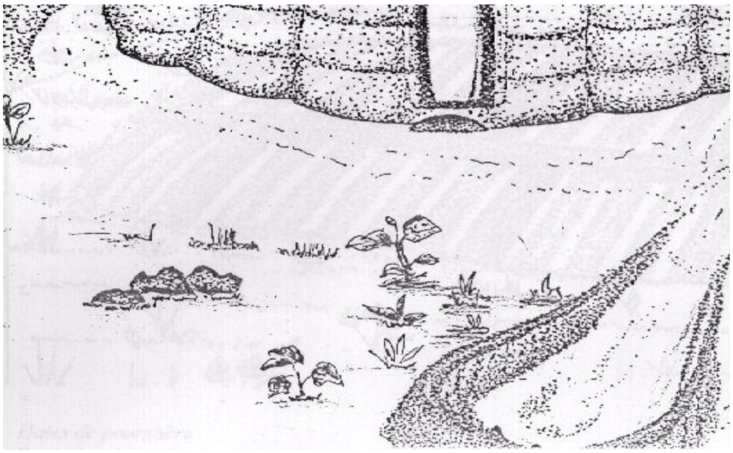
Source: Projet de Gestion des Ressources Naturelles

Figure A.4 : Tie-ridging, variant 2 ('billonnage en quinconce')



Source: Projet de Gestion des Ressources Naturelles

Figure A.5 : Water catchment



Source: Projet de Gestion des Ressources Naturelles

Appendix B.

The following reduced multinomial logit model of crop choice has been estimated (see Greene 2000, section 19.7.1):

$$\Pr[C_{hp} = j] = \frac{e^{X_{hp}\beta_j}}{\sum_k e^{X_{hp}\beta_k}}$$

where C_{hp} is the crop choice by household h on plot p, $j \in$ {cereals (with beans), other crops, fallow}, X a vector of explanatory variables, and β_j a crop choice-specific vector of coefficients. The following explanatory variables are included in the model: size of farm land owned by household (in log), number of adults equivalents in the household (in log), average number of livestock owned by household per plot, a dummy variable for high plot fertility ranking, dummy variables for rocky and gravelly soil on plot, dummy variables for light and steep plot slope, plot distance to home, dummy variables for indigenous soil and water conservation structures on plot, a dummy variable whether any adult member has permanently migrated in the household, the percentage of adult people not involved in cash activities in the household, and village dummies. We did not include a dummy for water catchments because all plots with water catchments grow cereals. Table B.1 gives the regression results.

The results of the model are intuitive. Households with more land are more likely to grow other crops (besides cereals) or to leave land in fallow. Households with more members are less likely to grow other crops or to have fallow land, presumably because of land scarcity. Fertile plots and plots without rocky and/or gravelly soil are more likely to be used for cereals. Plots that lie further from the tata are more likely to be grown with other crops or to be left fallow. Plots with indigenous soil and water conservation structures are more likely to be grown with cereals. Households who have at least one adult member in permanent migration are less likely to grow cereals and more likely to grow other crops or to leave land in fallow.

Based on the above regression estimates, the sample selection correction terms have been calculated according to the formulas derived by Dubin-McFadden (1984, equation 33):

$$\hat{\lambda}_j = \hat{p}_j \frac{\ln(\hat{p}_j)}{1-\hat{p}_j} + \ln(\hat{p}_{cereals})$$

where $\hat{\lambda}_j$ are the Dubin-McFadden selectivity terms, $\hat{p}_j$ the predicted probability, and $j \in$ {other crops, fallow}. These sample selectivity terms correct for sample selectivity bias if they are included in the regression for cereals only (as in table 6).

Table B.1: Multinomial Model of Crop Choice

Variables	Other crops		Fallow	
	coefficient	t-value	coefficient	t-value
Variable inputs and medium-term land investments				
ln(farm land) (ha)	**0.32**	1.67	**1.04**	3.40
ln(number of household members) (equivalent adults)	-0.27	-0.95	**-0.68**	-1.87
number of livestock (TLU)	0.11	0.64	-0.03	-0.12
Plot characteristics				
high plot fertility ranking (dummy)	**-0.92**	-3.84	**-3.00**	-6.55
rocky soil (dummy)	**-1.01**	-2.11	-0.68	-0.99
gravelly soil (dummy)	**-0.82**	-2.76	-0.80	-1.48
light slope (dummy)	**-0.67**	-2.44	**-0.92**	-1.93
steep slope (dummy)	**-0.98**	-2.24	0.75	1.29
distance to home (km)	**0.43**	3.07	**1.09**	6.14
Soil and water conservation techniques				
Stone bunds (dummy)	-0.74	-1.55	-0.48	-0.69
Tie-ridging (dummy)				
in Takouanta or Kounakogou	**-0.98**	-2.07	**-1.94**	-2.81
in Okouaro or Koutagou	**-1.22**	-2.72	0.03	0.04
Other type of ridging (dummy)	**1.06**	1.88	-1.37	-1.06
Household characteristics				
permanent migration of household member (dummy)	**1.00**	2.83	**0.90**	1.63
number of adults not involved in cash activities	-0.16	-0.30	0.33	0.40
Village fixed effects				
Takouanta (dummy)	**-1.08**	-2.35	-0.47	-0.78
Okouaro (dummy)	**-1.54**	-3.13	**-3.44**	-4.40
Kounakogou (dummy)	**-1.41**	-2.58	**-1.58**	-1.87
constant	**2.27**	2.91	0.62	0.54
Number of observations	509			
pseudo R^2	0.32			
Significance level regression (p-value)	0.0000			

Note: the outcome that crop choice is cereals is the comparison group. Coefficients with p-value of 0.10 or less are printed in bold.