Application of *zaï* and rock bunds in the northwest region of Burkina Faso; Study of its impact on household level by using a stochastic linear programming model.

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Abstract

Agricultural production in the northwest region of Burkina Faso is seriously endangered by soil erosion and an overall decline in soil fertility. In the past 15 years various anti-erosion methods have been adopted in this region with quite some success. The widespread promotion of rock bunds is an important example. Land conservation methods alone without increased efforts to maintain (or to increase) soil fertility levels does not suffice in the long run. In this article we focus on the potential impact of a combination of rock bunds and *zaï*, a local technology to improve water infiltration and efficiency of manure application. The analysis is carried out at farm level, with a stochastic linear programming model. It includes sequential decision making to cope with rainfall risks. The study reveals the important potential of rock bunds and application of *zaï*, and limitations due to labour and manure constraints. The techniques are largely applied on common fields. Changes in labour organization and use of manure have to be introduced before women may profit from these techniques on their individual fields as well. The results show that the impact on farm-level food security is more limited than is sometimes supposed on the basis of a simple extrapolation of plot-level results.

Résumé

La production agricole dans la région nord-ouest du Burkina Faso est sérieusement menacée par l'érosion des sols et la diminution générale de la fertilité des sols. Au cours de ces 15 dernières années, plusieurs méthodes de lutte anti-érosive ont été adoptées dans cette région avec un certain succès. Les diguettes en pierres (cordons pierreux) en constituent le meilleur exemple. Pourtant, à long terme, les méthodes de conservation des sols ne sont pas suffisantes, et les efforts pour le maintien et l'amélioration de la fertilité des sols doivent être intensifiés. Dans cet article nous nous concentrons sur l'effet potentiel des cordons pierreux en combinaison avec *zaï*, une méthode locale d'amélioration de l'infiltration de l'eau et de l'efficacité de la fumure. L'analyse est faite au niveau de l'exploitation à l'aide d'un modèle stochastique de programmation linéaire. Les risques pluviométriques et les décisions séquentielles afin de contrôler ces risques sont pris en compte. L'étude montre le potentiel important des cordons pierreux combinés au *zaï*, mais aussi leurs limitations dûes aux contraintes de main d'oeuvre et de fumier. Les techniques sont appliquées uniquement dans les champs communs et une réorganisation du travail et de l'accès au fumier est nécessaire pour que les femmes, elles aussi, puissent profiter de ces techniques culturales dans leurs champs individuels. Les résultats montrent que l'effet sur la sécurité alimentaire au niveau de l'exploitation est parfois plus faible qu'on ne le suppose à travers une (trop) simple extrapolation des résultats au niveau de la parcelle.

Keywords:

soil and water conservation, agricultural production, rainfall risk, household food security, whole farm analysis, linear programming, sequential decision-making, Burkina Faso, semi-arid regions of West-Africa

***Mots clés*:**

conservation des eaux et des sols, production agricole, risque pluviométrique, sécurité alimentaire des ménages, analyse des stratégies paysannes, programmation linéaire, décisions séquentielles, Burkina Faso, régions semi-arides en Afrique de l'Ouest

Introduction

Agricultural productivity is very low in the northwest region of Burkina Faso. Present yield levels seem to be obtained largely at the expense of the fertility of the land. Fallow periods are shortened or have disappeared and agriculture is extended into marginal areas without sufficient measures being taken to restore soil nutrient levels. Degradation of land, pasturelands and forests includes the rapidly loss of vegetative cover due to extensive livestock grazing, bush clearance and gathering of wood. As a consequence, wind and water erosion increases (causing a decline in the chemical status and physical structure of the soil), reducing further the productivity. Anti-erosion measures undertaken by farmers with or without the help of government programmes and non-governmental organizations (NGOs) are therefore of special importance in this region. The government of Burkina Faso has given priority to the provinces of Yatenga, Passoré and Bam (Figure 1) for their anti-erosion programmes.

Figure 1.

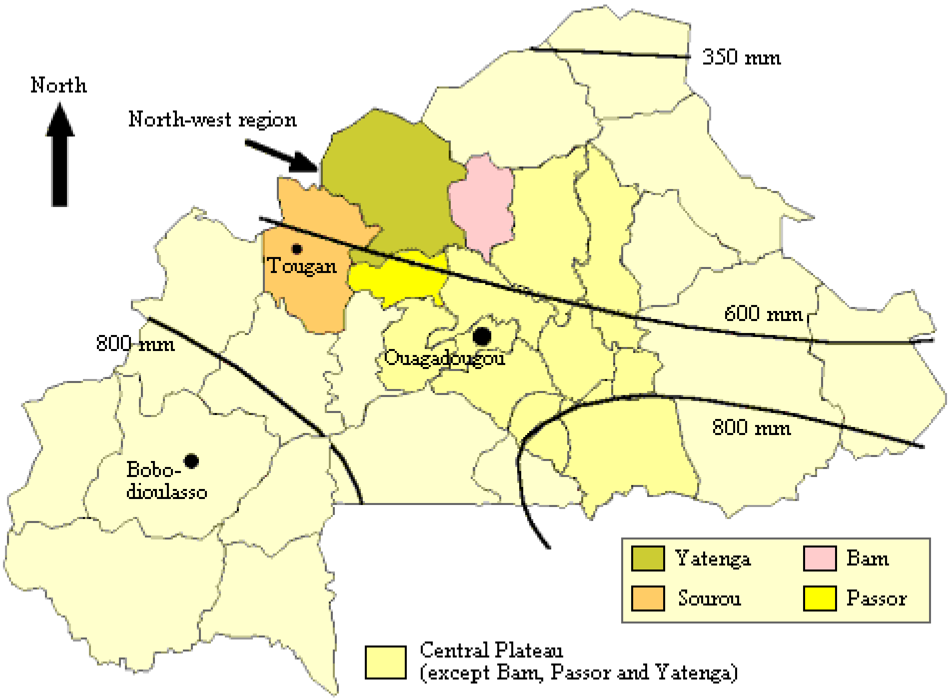


Figure 1. Map of Burkina Faso, showing rainfall isohyets, the north-west region, with the provinces of Yatenga, Passoré, Bam and Sourou and the Central Plateau.
Figure 1. Carte du Burkina Faso, avec les isohyètes, la région Nord-Ouest et ses provinces (Yatenga, Passoré Bam et Sourou) et le Plateau Central.

A well-known anti-erosion measure is the construction of small dikes of stones (rock bunds) to slow down run-off water flows, improve water infiltration in the soil and to reduce loss of top soil through wind and water erosion (Reij, 1983, 1996; Rochette, 1989). Areas where such rock bunds have been constructed are rapidly increasing and a large number of NGOs support the transport of stones and give technical assistance. Soil conservation alone will not solve the problems, certainly not in the long run. Recycling or input of soil nutrients has to be assured as well. In spite of efforts to promote the use of chemical fertilizers, they are hardly used in the region. Organic fertilization is increasing, but quantities are still well below the required levels. In order to apply organic fertilizer in an efficient way and to ensure optimal water availability some farmers are (re-)adopting (and adapting) a traditional technology called *'zaï'*: a hole is dug, organic manure is placed inside it and seeds are sown. Preparation is labour intensive and requires large quantities of organic manure. The potential impact of rock bunds and zaï depends therefore, in addition to soil characteristics, topography and rainfall, on social and economic factors like organization of labour, access to manure, etc. In this article the impact is studied of a combination of rock bunds and *zaï* on food security at household level using a stochastic linear programming model.

The northwest region of Burkina Faso

The northwest region covers an area of 30,817 km^2 (i.e. 11% of Burkina Faso) and is situated in the Sudano-Sahelian zone. The region comprises the provinces of Yatenga, Passoré and Bam, which belong to the Central Plateau, and Sourou (Figure 1). Average annual rainfall is about 400 (north) to 700 mm (south) and is highly variable in both space and time. Natural vegetation is of the savannah-type, dominated by grasslands, dotted with trees and shrubs. The region has an average population density of 41.1 inhabitants km^{-2} with an average growth rate of 1.9%. Population density is highest in Passoré and lowest in Sourou (55 versus 28 inh. km^{-2}). The largest part of the region is populated by sedentary farmers. Millet is mainly cultivated in the northern parts, white sorghum in the south, covering 80 to 90% of the cultivated areas (INERA, 1994). Produce is mainly used for auto-consumption, with a requirement of 190 kg $inh.^{-1}$ (Bakker-Frijling and Konaté, 1988). Average cereal production (1984 - 1993) was about 190 kg $inh.^{-1}$, a little less than the national average (220 kg $inh.^{-1}$). Cereal production varies considerably from one year to another, e.g. with a value of 90 kg $inh.^{-1}$ in 1990. Raising of cattle, small ruminants and poultry is important, especially to raise money for purchasing cereals when stocks are running out.

Rock bunds

The rock bunds are placed on contour lines. Their length is variable (the bunds must not be too long), with wings folded in the upslope direction. There exist several ways of constructing rock bunds: with or without ditches, with single rows of stones or with more stones piled up against each other (Kaboré *et al.*, 1994; Rochette, 1989). Also the distance between the rows and the height (and width) of the rows differ, depending a.o. on the slope of the land. In practice, because of the difficulty in finding stones and the cost of transport, the distance between bunds is often quite large (sometimes exceeding 50 meters).

The success of rock bunds is related to their potential to recover degraded fields, and to increase yields. Erosion may decrease considerably with rock bunds (from 12 to 4 t ha^{-1} $year^{-1}$;, de Graaff, 1996: p. 170). The impact of rock bunds on yields is not yet very clear. In earlier times yield increases of almost 100% were reported (see e.g. Reij, 1983). However, such increases often appeared to be due to the combined effect of rock bunds and increased fertilization. Effects of rock bunds depend on soil type, on the position of the field on the toposequence, and - not least - on rainfall. Rock bunds influence yields both in the short as in the longer run. In the short run, rock bunds especially seem to improve the water balance; in the longer run nutrient availability may gradually increase (de Graaff, 1996: p. 174).

Estimates of the cost of rock bund construction vary considerably and depend on the organisation of the land conservation, how the transport of stones is arranged (by lorries or by carts and bikes, or by head, by the local population themselves), the distance from the location where the stones are to be collected, the time spent by NGO-personnel to train the farmers, the cost of technical support, of preparatory activities etc.

Zaï

Zaï ("water pockets") is an intensive technique for the management of manure and the preservation of water. In Yatenga in the north of Burkina Faso it is an ancestral practice used for regenerating the poorest parts of the fields. Nowadays it is widespread in all zones of the country where deterioration is grave. The dug holes have a depth of 10 to 15 cm and a diameter of 15 to 20 cm. The organic manure creates a micro-environment which allows the plant better resistance against drought and as a result the yields improve substantially. In Yatenga the yields amount to 2,000 kg ha^{-1} against 900 kg ha^{-1} on untreated fields (INADES, 1993). In a village such as Donsin where much land is deteriorated and *zaï* has recently been introduced, average yields of 1,200 kg ha^{-1} have been found in 1993 with maximum levels of more than 4 t ha^{-1}. (Kaboré *et al.*, 1994). *Zaï* helps to improve the yields of crops, but demands considerable effort in terms of labour: about 780 h ha^{-1} for the preparation of the *zaï* (digging holes, transport of manure, seeds), for instance digging between 20,000 and 25,000 holes ha^{-1}. The digging of holes takes place at a time when the farmers are not too busy (*zaï* can be sown earlier, see Robins & Sorgho, 1994). The quantity of required compost depends on the number of holes per ha. Between 4 and 18 tons of compost has to be produced for each hectare of *zaï* (INADES, 1993; Kaboré *et al.*, 1994; Sawadogo, 1996). Nevertheless, *zaï* remains a commendable technique (Kaboré *et al.*, 1994; Sawadogo, 1996).

Materials and methods

A linear programming (LP) model for a farm household, representative for farm households on the Central Plateau, is used. In the LP model, decision variables and parameters are defined. Decision variables correspond to decisions to be taken, parameters to exogenous factors (e.g. yields, prices, and labour times), as described in detail by Maatman & Schweigman (1995) and Maatman *et al.* (1996). Below a summary description is given.

Base model without zaï and rock bunds

The base model describes crop production decisions during one growing season, and consumption, storage and marketing strategies during the period from the beginning of the harvest period until the next harvest (Figure 2).

This period is called *target consumption year*. Production decisions taken into account include:

a. crop choice: the mono crops maize, red sorghum, white sorghum, millet and groundnuts, and the mixed crops red sorghum/cowpeas, white sorghum/cowpeas, millet/cowpeas;
b. land category: dependent on the location of the toposequence (low or high lands), on the distance from the compound (< 100, between 100 - 1000, or > 1000 m), and land ownership (common or individual fields);
c. applied dose of organic manure (0, 800, 1000, 4000 or 8000 kg ha^{-1});
d. sowing dates: dependent on crop and land category;
e. levels of intensity of weeding (intensive or extensive).

Figure 2.

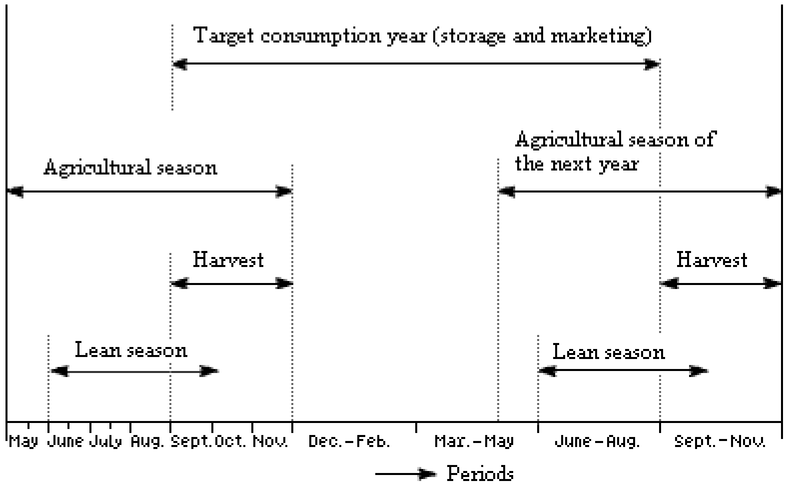


Figure 2. Schematic representation of the planning period.
Figure 2. Représentation schématique de la période de planification.

A key feature in the model is the concept of plot. This is a piece of land characterized by these five properties. *'Representative plots'* refer to current combinations of crops, land categories, and agricultural methods (c - e), and *'alternative plots'* to other combinations. The area of each plot is a 'decision variable'. Their values correspond to the production decisions what, where, how much, how and when should be cultivated. Key elements of the LP model are the *constraints* of *land* (per category), *labour*, *organic manure* and *fallow*. These constraints prevent required amounts of resources exceeding available amounts.

For labour constraints, the growing season was split up into time periods of two weeks in the beginning and one month later in the season. Labour includes time spent working on the land, and walking to and from the fields.

Fallow is dealt with by postulating that supplementary to each plot a piece of land is left fallow. The size of this piece of land, as fraction of the corresponding plot depends on category of land, crop and manure level.

Decisions on sowing, resowing, timing of weeding and intensity of weeding are not made at one time, but progressively during the growing season dependent on observed rainfall, germination of the seeds, appearance of herbs, etc. In fact, production strategies are of a *dynamic* nature. Decisions are taken sequentially. This process of sequential decision-making is one of the farmers' most important ways to control risks due to uncertain rainfall. Therefore, a three-stage stochastic programming model has been developed. The first stage of the installation of the growing season covers the months May and June (Figure 2).

In stage one, three scenarios of *observed* start of the growing season are distinguished: 'late', 'normal' and 'early'. The number of days favourable for sowing in the labour constraints is a critical parameter: if planted during these favourable days the plants will come up, and early growth will be successful. The number of favourable sowing days is determined by the start of the growing season.

In the second stage, covering the months July and August, the rains can be 'bad', 'average' or 'good' in terms of amount and distribution. When decisions in the first stage on e.g. sowing have to be taken, rainfall in the secod stage is *uncertain*. Use is made of the probability distribution of rainfall in this period. It is assumed that there is an equal probability of having 'bad', 'average' or 'good' rainfall in this stage that corresponds to 'pessimistic', 'average' or 'optimistic' yield levels. The decisions made during this stage include the choice of late sowing, and of intensive or less intensive weeding. It can also be decided to abandon certain plots, planted during the first stage. The rainfall regime influences the labour time for intensive and less intensive weeding and yields.

The third stage consists of the target consumption year. During this stage, decisions on consumption, storage and marketing are made. This period is again divided into several periods of time to analyze the strategies at different times of the year. Decisions on marketing relate to quantities sold and purchased. The nutritive balances express the cereal and the non-cereal consumption in terms of *nutrients* (energy and proteins). In the *stock equations* for all agricultural products, storage losses, and seed reserves are included as well. *Financial balances* contain also interest rates, and non-agricultural incomes and expenses.

Finally, restrictions are included in the model to ensure that the calculated patterns of consumption correspond to observed ones. Examples are the restriction on the consumption of red sorghum, which is mainly used for beer, and the condition that a major part (85%) of the meals should consist of cereals. A certain level of self-sufficiency (60%) is also always required.

The main objective of all strategies of the representative household is to try to prevent, or if that is not possible, to minimize shortages of energy and proteins during the target consumption year. If these shortages can be avoided, then a stock is kept for the harvest period of the next year. If these stocks are sufficient, then the revenues are maximized. If revenues are indeed obtained, a fraction is spent on a food security safety stock for the next year. The sequence of all these objectives is dealt with in one objective function, by a proper choice of weigthing coefficients. The model is a typical multiple-goal model.

Given a set of values of first stage decision variables, and given the rainfall scenario for the first stage (late, normal or early start) and the second stage (bad, average or good), second-stage and third-stage decision variables can be computed simultaneously. The values of the first stage decision variables are determined by optimizing the *expectation* of the value of this objective function. The stochastic programming problem can be formulated as a linear programming problem.

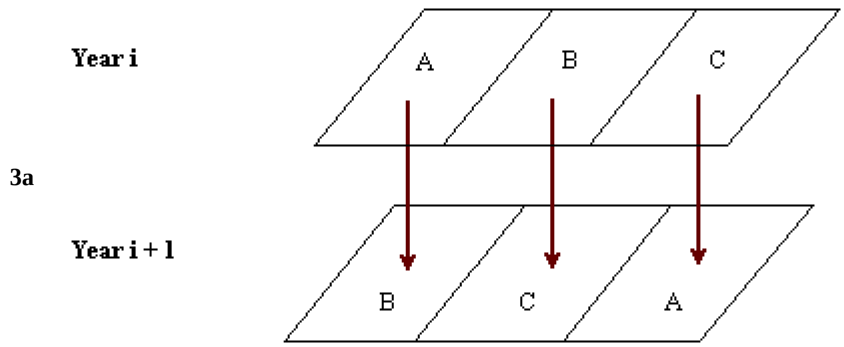
Integration of zaï and rock bunds

In the central and northwest regions, *zaï* is practised on the higher fields, and often on the most deteriorated parts, the *zippélé* in the local language, (Kaboré *et al.*, 1994; Sawadogo, 1996). In the *zaï* only sorghum and millet are sown, generally intercropped with cowpea. The current practice is that farmers sow in the same *zaï* for several consecutive years, while organic manure is applied only once (i.e. just after the holes have been dug); this has been taken into account in the LP model. First, a distinction is made between the application of *zaï* on existing plots on higher fields and on new *zippélé* fields. For the practice of *zaï* on the higher fields we take a cycle of three years and an initial dosage of 9,000 kg ha^{-1} of organic manure if sorghum is grown, and 6,000 kg ha^{-1} if millet is grown. This cycle can be dealt with by dividing the plot where *zaï* is practised into three equal parts: one in which people dig new holes and apply organic manure, one in which existing holes are used for sowing (without additional fertilization) and one, in which the holes are no longer used and the land is ploughed and sown as usual (the assumed schedule is shown in Figure 3a). In the next year this last part will be used to dig new holes again. On the *zippélé* the *zaï* technique is applied to regenerate the land and the cycle is five years (Figure 3b), after which the land will be categorized as high land.

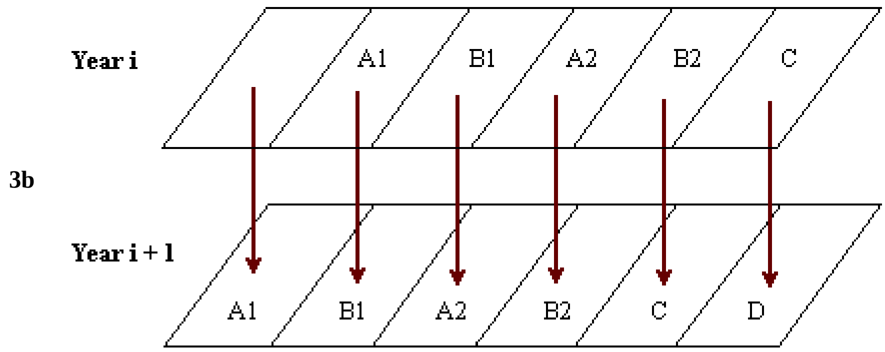
The model has been modified in terms of the constraints of land and labour. The land constraints take into consideration the area of *zippélé* that has been regenerated and added to the higher land through the practice of *zaï* (a fith in a single year). For labour, the digging of holes can start before the growing season (March, April) and continue until sowing. The work is only done by adult men during a few hours per day only, owing to the great physical effort demanded. Data on yields, agricultural calendars and labour requirements have been obtained from Kaboré *et al*. (1994), and Sawadogo & Ouédraogo (1996). On the higher fields the yields of the *zaï* increase enormously in the first year (between 4 times for red sorghum and 2.5 times for millet, in comparison to the no manured situation. The yields on the *zippélé* are in the first year 20% lower compared to the higher fields. Yields on *zippélé* and higher fields decrease to 60% of first year levels in the second year and to 40% in the third year. Labour requirements for digging holes are 450 hours ha^{-1} on the higher fields and 650 hours ha^{-1} on the *zippélé, and* for fertilization 250 hours ha^{-1}. Weeding hours increase (between 15 and 25%), especially during the first weeding, in the first year when new holes are dug and manure is applied, and also in the third year on the *zippélé*.

In the model, rock bunds are constructed only on all common fields and individual fields within a distance of 1000 m from the compound. Yields on fields with rock bunds are set on average 12,5% (between 10 and 15%) higher than yields on comparable fields without rock bunds. Labour requirements remain the same, except for harvest time which is dependent on yield-levels. Finally, we assume that both rock bunds and *zaï* decrease yield variability, as they promote water infiltration. However, since on this subject almost no data were available, and the results of our experiments and interviews with farmers (Sawadogo, 1996) were somewhat ambiguous (especially with respect to the rock bunds), low values are chosen: for *zaï* the decrease in the variability of yields (i.e. coefficient of variation) is about 8%, for rock bunds about 5%, and for both measures together about 12,5%. These percentages are applied to estimate the influence of *zaï* and rock bunds on yields in good and bad scenarios of rainfall (in the second stage). The objective function to be optimized is the same as for no *zaï* and rock bunds.

Figure 3.



A: Digging of holes, application of manure
B: Sowing in the holes, prepared one year ago
C: Ploughing by hand



A1: Digging of holes, application of manure
B1: Sowing in the holes, prepared one year ago
A2: Digging of new holes between the old ones, wich are no longer used; application of manure
B2: Sowing in the holes, prepared one year ago
C: Ploughing by hand
D: Cultivation as done on normal arable land

Figure 3. Schedule of cultivation cycles for *zaï* on existing plots (3a) and on *zippélé* (3b).
Figure 3. Schéma des cycles de culture pour la pratique du *zaï* sur les terres cultivables (3a) et sur les *zippélé* (3b).

The LP-model is run for two different farm-types:

1. no *zaï* on the fields and no rock bunds, and
2. *zaï* and rock bunds. For the rest, the two farm types are identical, and representative for the region: households of 10 members, of which 5 children (below 12 years); total land of 6,4 ha (distributed over less fertile upper (90%) and lower (10%) slopes; 84% consisting of common fields and the "average" manure availability is 2,000 kg. Furthermore, runs are made to investigate the effects of increased manure availability.

Results and discussion

Base model without zaï and rock bunds

Results for the situation without *zaï* and rock bunds are described in detail by Maatman *et al.* (1996). Strategies differ much according to rainfall patterns. This can best be illustrated for two extreme situations:

1. a 'late' start of the growing season and bad rainfall in the second stage: time for sowing and growth of weeds are limited; all weeding can be done intensively. Production is low.

2. an 'early' start of the growing season and good rainfall in the second stage: much more labour time for sowing is available. Labour time for weeding is very restrictive. Part of the fields has to be abandoned in the second stage due to a lack of labour. Production is relatively high.

Table 1. Selected results of the linear programming model, for a representative farm: 1) without rock bunds or the possibility to apply *zaï*; 2) with rock bunds and *zaï*.

Tableau 1. Résultats choisis du model de programmation linéaire pour l'exploitation agricole représentative: 1) sans les cordons pierreux et le *zaï*; 2) avec cordons pierreux et le *zaï*.

	Farming system no *zaï*, no rock bunds			**Farming system with *zaï*, rock bunds**		
Stage 1: sowing (ha)						
☐ red sorghum	0.27			0.15		
☐ millet	2.44			2.44		
☐ cowpeas(intercropped)	(1.32)			(1.03)		
Total surface sown	2.71			2.59		
Rainfall in second phase ---->	"bad"	"average"	"good"	"bad"	"average"	"good"
Stage 2: sowing (ha)						
☐ maize	0.17	0.16	0.11	0.13	0.13	0.13
☐ millet	0.67	0.52	0.04	0.66	0.14	-
☐ groundnuts	0.12	0.21	0.35	0.19	0.70	0.12
☐ (cowpeas)	(0.09)	-	-	-	-	(0.12)
Total surface sown	0.96	0.89	0.50	0.98	0.98	0.45
Total surface (ha)						
☐ sown	3.66	3.59	3.20	3.56	3.56	3.28
(with *zaï*)	-	-	-	(0.67)	(0.67)	(0.67)
☐ cultivated int.[1]	3.66	2.71	1.88	3.56	2.75	2.06
☐ cultivated low.[2]	-	0.88	1.12	-	0.81	1.07
☐ harvested	3.66	3.59	3.00	3.56	3.56	3.13
Production (kg)						
☐ cereals	927	1343	1500	1074	1357	1675
☐ groundnuts	17	69	171	35	230	228
☐ cowpeas	18	33	45	28	44	61
Sales (kg)						
☐ cereals	123	75	149	134	5	62
☐ groundnuts	0	37	11	0	82	66
☐ cowpeas	0	18	30	0	34	46
Purchases (kg)						
☐ cereals	264	378	471	272	399	466
☐ groundnuts	31	0	0	31	0	0
☐ cowpeas	0	0	0	0	0	0
Shortages						
☐ in 1000 kilojoules	9581	1895	0	7042	0	0
☐ in proteins (in 1000 gr)	25.6	0	0	15.4	0	0
Reserve stock (kg) (cereals)	0	0	223	0	125	918
Revenues (FCFA)	0	0	0	0	0	2253

Notes:

1) Cultivation Int. (intensive cultivation): timely and efficient weeding.

2) Cultivation Low (less intensive cultivation): reported and more superficial weeding.

These results for the Central Plateau are very much in agreement with observed practices. As a description of the farmers' strategies the three-stage model seems to be fairly appropriate. By adapting their strategies to rainfall conditions the farmers reduce the risk of poor harvests. This result is quite understandable, if we take into account that the food situation of the farm is extremely delicate. Only in good rainfall years, is consumption enough. The household in the northwest region is not self-sufficient in food production (Table 1). It produces only between 51 (poor rainfall season) and 93% (good rainfall season) of its nutritional requirements. In poor rainfall years, non-agricultural income is not enough to compensate for the low production levels and subsequently serious shortages occur. Farmers intend to rely on flexible cropping systems, for instance the cultivation of crops like millet, which can endure low levels of crop management. For instance, weeding of millet can be postponed or carried out less intensively without reducing yields too much. Maize is an important crop, since it is harvested during the first weeks of the harvest period, just before the harvest of the (large) millet fields. Because reserve stocks from the preceding year are often absent, the harvest of maize helps to decrease consumption expenses and to minimize, or even prevent, food shortages.

Adapted LP model: with zaï and rock bunds

The introduction of *zaï* and rock bunds leads to an increase in crop production (Table 1), but it is still not sufficient to feed all members of the household. Only when rainfall is good, does production come close to meeting food requirements. The farm does not need all its revenues to buy food, but is able to save some income for other purposes. The energetic value of the total crop production increases for bad, average and good rainfall scenarios with respectively 19, 18 and 16% (compared to the situation without *zaï* and rock bunds). *Zaï* apparently is of interest. It is applied on almost 20% of the cultivated land. The adoption of *zaï* (and the presence of rock bunds) has only a marginal effect on the total area cultivated. The impact of *zaï* on weeding labour does not restrict the area of the cultivated land. This is due to the agricultural calendar of *zaï*; if sown early some weeding can be done before the peak-periods. *Zaï* is not used for the reclamation of *zippélés*, instead it is used on the (low fertile) upper slope fields. Sensitivity analyses show that *zaï* is only used on *zippéles* if less land is available.

Agricultural production can increase considerably if more organic manure is available, even in bad rainfall years (Figure 4). This intensification of manure use is not limited by increased labour requirements. It leads to a change in weeding practices. A few fields are cultivated with high doses of manure and with intensive weeding, whereas on other fields no manure is applied and weeding is done extensively. Manure, however, is a very scarce resource, so that more manure requires more animals with associated risks for degradation of pastures.

Figure 4.

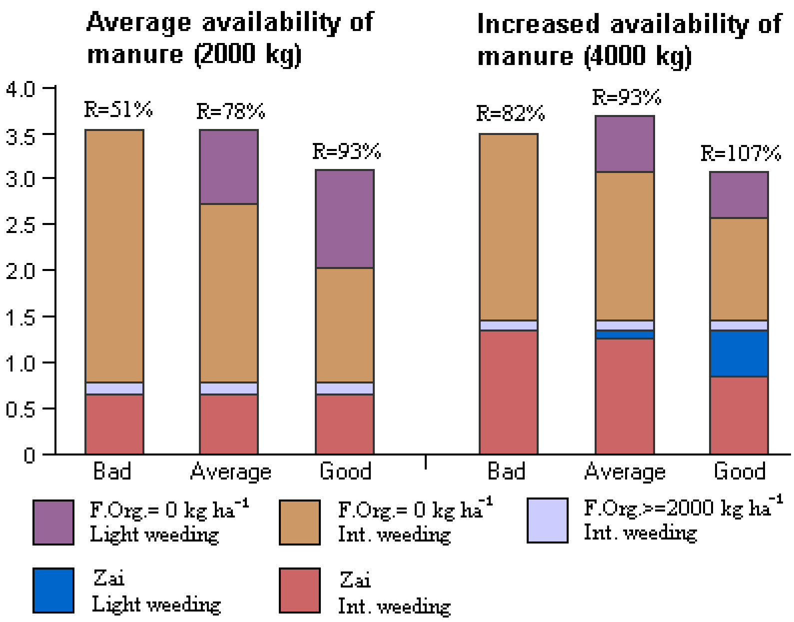


Figure 4. Cultivated areas (ha) and production (R in % of energy requirements) for a farm with current and increased manure availability under three rainfall regimes (bad, average, good).
Figure 4. Superficies cultivées (ha) et production (R en % des besoins en energie) pour une exploitation avec des valeurs moyenne et plus élevée de disponibilite en fumure organique, sous trois scénari pluviométriques (mauvais, moyen, bon).

Analysis for different rainfall scenarios during the first stage of the rainy season gave very much similar results as shown above for a normal start of the rainy season. The application of *zaï* is not hampered by a late start of the season as the holes can be dug before the rains start. The *zaï* sequence as proposed in this study reduces the flexibility of the production system, since every year some holes have to be dug and sown, more or less independent of the rainfall scenario at the beginning of that season. However, the *zaï* technology in practice is not that rigid, since decisions on the sowing dates of the *zaï*-holes can easily be adapted to the rainfall in the beginning of the rainy season.

Final Observations

The results show the important potential of the combination of rock bunds and the local technology *zaï*. Both technologies conserve water and land. In addition *zaï* appears to be a means to increase the efficiency of the very limitedly available manure application. This may induce more efforts to collect manure (improvement of livestock management methods, production of fodder crops, etc.). It is furthermore noted that *zaï* is particularly promising when soils are very poor. When soil fertility is higher the *zaï* technique may not be the most effective one, since *zaï* hampers the introduction of animal traction for ploughing and weeding.

Zaï can be an interesting technology for the women's individual fields, since their soils are usually poor and their size small. However, until now, the *zaï* technique has only been applied on common fields. Major problems for extension of this practice to the individual fields include questions such as: who will dig the holes? how to obtain the required quantities of manure? and, in particular, how to secure land rights in order to be able to profit from the effects of *zaï* in later years.

We conclude this article with some conclusions. *Zaï* and rock bunds are important technologies to increase food production. However, the impact of *zaï* and rock bunds on food production is more limited than sometimes suggested on the basis of (too) simple extrapolation of plot-level results. This is supported by some in-depth field studies in the Yatenga region (Atampugre, 1993). The application of *zaï* and rock bunds is restricted by labour requirements at the household and village level, by manure availability and by uncertain land rights. The gradual increase in fertilization rates is the most promising next step to increase food production. The developed model has been a useful tool to analyse the merits of *zaï* and rock bunds practice.

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