



Flood recession agriculture in the Senegal River Valley

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Abstract

The purpose of this paper is to explore the system dynamics, the importance and future of the low yielding flood recession farming system as practiced in the Senegal River Valley. This is discussed in relation to the introduction of irrigated agriculture into villages of the valley and to the hydrological changes of the Senegal River caused by the construction of the Manantali dam and the Sahelian drought of the 1970s and 1980s. The paper is based on data collected during three months of fieldwork in three villages located in the Podor region in Senegal. The fieldwork focused on the physical and ecological aspects of the flood recession farming system. Data was obtained through semi-structured interviews on the household level and with groups of village elders and local agricultural leaders. On the regional and national level interviews were carried out with the agricultural and water management authorities.

The flood recession farming system is based on natural irrigation and fertilization of the flood plain. Sorghum, beans and melons are cultivated on the remaining soil moisture from the yearly inundations of the river valley in August and September. Flood recession farming receives no controllable input other than land and labour and therefore has a very high net return to energy expenditures. The study however shows that the labour productivity and the net income from the input intensive irrigated farming system far exceed that of the traditional flood recession farming. Nevertheless, the output from the recession farming is very important to household subsistence since the general energy requirements of the households are far from covered by the irrigated farming. The recession agriculture would then support the household subsistence during

months where other contributions to the household subsistence are limited. Furthermore, results of the recession farming are strongly affected by the limited flooding that prevailed during the investigated period.

The management of the Manantali dam in Mali and the varying precipitation in the upper part of the river basin cause large yearly variations in river valley inundations and thus affects the yield from recession farming. Since the farmer cannot control the access of river water to the recession fields there exists no incentive for the farmer to invest in the development of the flood recession farming system. If the system is not further developed, the future potential for recession agriculture is likely to decrease as population and subsistence demands increase and irrigated agriculture is further developed. Therefore, the future of flood recession agriculture depends for a large part on the willingness of the dam management authorities to ensure a yearly and stable inundation of recession land in years of limited natural flows. This would eliminate the insecurity of water availability and justify investments in and further development of traditional farming practices.

Keywords

Flood Recession Agriculture, Manantali dam, Senegal River Valley.

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The large rivers crossing the arid and semi-arid parts of Africa have figuratively been called the lifeline of the impoverished nations (Darkoh, 1992). Through the last few decades man's impact on these rivers has grown rapidly with the building of dams, which have been constructed to generate hydroelectricity and to support down stream irrigated agriculture in order to meet rising demands for water, power and food (Lewis & Berry, 1988). In the Sahel, during the 1970s and early 1980s, competition for river valley resources rose due to the Sahelian drought, as peo-

ple and animals from the surrounding drought affected drylands were attracted to the fresh water and the green pasture of the valleys (Barrow, 1987). With the drought, attention was also drawn to the high development potentials of the river basins for irrigated agriculture (Sahli, 1982). Dams were constructed to stabilize and ensure a constant availability of irrigation water from the rivers many of which are dominated by large seasonal fluctuations in their flow patterns (Lewis & Berry, 1988). A stabilization or disruption of the natural river dynamics of

such rivers affects the yearly inundations of the flood plain to which down stream ecosystems have adapted. These inundations support traditional agricultural systems, regeneration of grazing- and wood lands, wildlife populations, ground water replenishment and fishing resources (Barrow, 1987; Adams, 1990; Salem-Murdock et al., 1993; Horowitz & Salem-Murdock, 1993). The damming of the rivers and the spread of irrigated agriculture therefore interferes with traditional patterns of land and resource use on the flood plains (Sahli, 1992; Barrow, 1987). It is within this development that the paper takes its point of departure by investigating the importance and future role of traditional flood recession agriculture in the Senegalese part of the Senegal River Valley.

Development of the Senegal River Basin

In the late 1970s and 1980s comprehensive development of irrigated agriculture took place in the Senegal River Valley as a response to the drought and the desire of the Senegalese government to improve the utilization of the river valley resources (Moris & Thom, 1990; Salem-Murdock et al., 1994). Already in 1972 a river basin management authority for the Senegal river, OMVS (Organisation de Mise en Valeur du Développement du Fleuve Sénégal), was formed by the Mali, Mauritania and Senegal governments to develop the river basin resources by constructing two dams. The Manantali dam was finished in 1988 and is located in Mali on the Bafin river, a branch of the Senegal River. The Diama Dam was finished in 1986 and is located in Senegal at the mouth of the Senegal river at St.Louis. The Manantali dam was con-

structed to ensure a production of hydroelectricity for the three member states and expand irrigation in the Senegalese and Mauritanian river valley's. However, mainly due to political and economic disagreements within the OMVS, no hydroelectricity has until today (1999) been produced by the Manantali dam project. Furthermore, the two dams opened the possibility for navigation on the Senegal river by creating a river-based opening from Kayes in Mali to the Atlantic Ocean but there is hardly any river transport on the Senegal River (LeMarquand & Iwra, 1990; Block, 1993). The planned development initiatives have had a large effect on land use practices of the flood plain, especially on the agricultural development in the river valley (Mounier, 1985; Horowitz & Salem-Murdock, 1993; Moris & Thom, 1990; Park, 1993). More than a decade has passed for the irrigated farming system to develop and today it represents an alternative high yield agricultural production compared to the traditional flood recession farming system. However, in a large number of villages in the middle and upper river valley, farmers still depend on traditional flood recession agriculture and practice recession farming parallel to the cultivation of irrigated crops (Salem-Murdock et al., 1993).

The Senegal River Valley

The Senegal River has its source in the Fouta Djallon Mountains of Guinée. It crosses the western part of Mali and for the rest of its course constitutes the border between Senegal and Mauritania (Rasmussen et al., 1999). The river basin covers approximately 350 000 km² and consists of three main regions; the upper basin, the lower basin, also called the river valley, and the delta region (Salem-Murdock et al., 1994). The river valley begins at Bakel in Senegal and from there the river flows 800 km until it reaches the delta and the river mouth in St.Louis (OMVS, 1979). The river valley consists of a 10 - 25 km wide flood plain, surrounded by semi-desert and the river valley covers approximately 10 000 km² (Salem-Murdock et al., 1994). The investigated villages are located in the Podor area, situated in the lower-middle river valley, see Figure 1.

Data collection

The empirical material is based on fieldwork carried out in January - March 1998 in three villages located within a 10 km radius of Podor. The fieldwork mainly focused on the physical and ecological aspects of the flood recession



Figure 1: *The Senegal River Basin. Modified from Rasmussen et al. (1999). Graphic: Kent Pørksen*

farming system and did not include studies on social differentiation and tenure. Data was obtained mainly through semi-structured interviews. A comprehensive study using questionnaires on household information, livelihood strategies, agriculture (history, dynamics, input, output, preferences) and environmental changes was carried out among 11 households. Semi-structured interviews were held with groups of village elders and local agricultural leaders. A second and minor questionnaire focusing on quantitative information on crop yields and sale was addressed to 100 farmers randomly selected in the investigated villages. On the regional and national level, interviews were held with the agricultural and water management authorities.

Study area

Investigated villages

The villages N'Gaolé and Diatar are located on the bank of the Senegal river east and west of Podor. The third village, Goumel, is located on the bank of the Douée river, a tributary branch of the Senegal River approximately 5 km south-west of Podor. These villages represent the agricultural diversity in the area. In N'Gaolé and Goumel the farmers practice a combination of irrigation and flood recession farming, whereas, only irrigation farming is practiced in Diatar. The three investigated villages differ significantly in size and population. N'Gaolé, which was a former fishing village, has almost 1600 inhabitants but the decline in rainfall and flood plain inundations has caused a decline in fishing and flood recession farming. This created food shortages with the result that fishing became a subsistence activity and farming the main occupation. Goumel is a small village with a population of approximately 175 inhabitants. Before the drought in the 1970s, Goumel was an agro-pastoral village consisting of approximately 30 households living on the dry uplands, the *jeeri*. During the drought most of their animals died and the households with surviving animals moved south in search for fodder. The rest of the villagers moved permanently down in the river valley and took up subsistence farming. Diatar is the third and largest investigated village with a population of 2450 inhabitants. Diatar was traditionally an agricultural village. Before the drought in the 1970s both rain fed farming in the *jeeri* and flood recession farming in the valley was practiced. With the drought it became difficult to cultivate the *jeeri* and inundations were severely limited, which reduced the potential for re-

cession farming. The floods never regained their former size and at the time when floodwater started to return to the recession area of N'Gaolé and Goumel, less water returned into the recession area of Diatar. Today the limited flooding of the Diatar area has led to the dominance of irrigated farming in the village, whereas farmers in N'Gaolé and Goumel still practice irrigated as well as flood recession agriculture.

Climate, hydrology and soils of the lower and middle valley

The Senegal River Valley is dominated by three seasons: The dry and hot season from February to May, the rainy season from June to September and the dry and cold season from October to January. The average annual temperature at Podor is approximately 30 °C and the annual rainfall in the Podor area is approximately 200 mm/year. Podor has experienced a 44 % reduction in annual rainfall when comparing the average rainfall from 1918-1969 with the average from 1970-1987 (Gibb et al., 1990; Euroconsult/RIN, 1990).

The source of more than 90 % of the annual water flow in the Senegal River originates from the rain that falls from July to November in the Fouta Djallon Mountains. Approximately 70 % of the total water flow in the Senegal River occurs during the wet season (Euroconsult/RIN, 1990; Lewis & Berry, 1988). Thus, a close correlation is evident ($R^2 = 0.83$) when comparing the river flows at Bakel with historical river levels at Podor. This underlines the profound relationship between the hydrological processes of the upper basin and lower basin, and further illustrates that the size of the flood in the river valley is almost solely controlled by the hydrological processes of

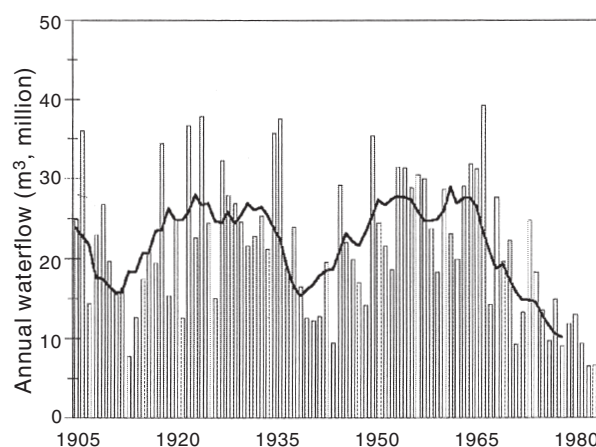


Figure 2: Annual water flows at Bakel. The curve illustrates a seven-year average from 1903 to 1986 which is the full period for which an undisturbed natural record is available. Based on data from Gibb & Partners (1990).

the upper basin. Large inter-annual variations in the water flow of the Senegal river prevails, see Figure 2. This changes the potential flood recession area each year. Often it is only part of the inundated area that is farmed. If the area is only briefly flooded, the soil will not absorb enough water to sustain crop growth until maturity as well as flooding for a period longer than 12 weeks creates unfavourable farming conditions (Euroconsult/RIN, 1990). The optimal duration of the inundation with regard to flood recession agriculture is three to four weeks (Euroconsult/RIN, 1990).

The pedological development of soils in the Senegal River Valley are strongly influenced by the arid climate and the dominating alluvial processes (Euroconsult/RIN 1990). In general the soils are poor and of low fertility due to the climatic conditions and the limited vegetation cover (Black & Sessay, 1997). However, when discussing the farming potential of a certain soil type within the river valley, the preferred land use and the valley topography is very important. The access to water, along with the water retention capacity of the soil and hence the risk of crop failure in case of drought or the need for irrigation, are some of the major soil related factors influencing the value of agricultural land within the valley (Tabor, 1993). The local topography which controls the accessibility of river water and surface runoff is also an important factor for agriculture. It is thus the local topography which determines the location on the flood plain of the dominating land use: flood recession agriculture, irrigated farming and vegetable gardens.

As illustrated in Figure 3 and described in Table 1, flood recession agriculture is practiced on the low-lying

Hollaldé and Faux Hollaldé soils of the flood plain, also called the *cuvette*. These soils have a high water retention capacity and a high clay content. In the *cuvette* sediments carried into the area during the inundation brings along a natural fertilization of the soil. This allows for cultivation of the land without fallow periods and without use of chemical inputs. The irrigated fields are located on the higher silty to sandy Fondé soils close to the river. These soils have moderate retention capacities with high infiltration rates and are easy to cultivate.

Land use

Land use history

The traditional land use of the flood plain was closely adapted to the river valley ecology and hence to the water dynamics of the river. The flood plain resources were important for both agricultural practices, as in Diatar, but also for fishing and herding, as in N'Gaolé and Goumel. Together the different villages occupied and utilized the flood plain resources during different periods of the year. In the rainy season when the valley was inundated and fertilized by deposited material the fishermen moved their activities from the river into the flood plain and its channels. After the rains, when the water receded, flood recession farmers cultivated the *cuvettes*. At the beginning of the hot and dry seasons the crops, mainly sorghum, were harvested. A few months after the rain, when the uplands turned dry, the pastoralists and their herds started arriving to utilise the freshwater and to forage on the last green pasture and crop residues (Moris & Thom, 1990).

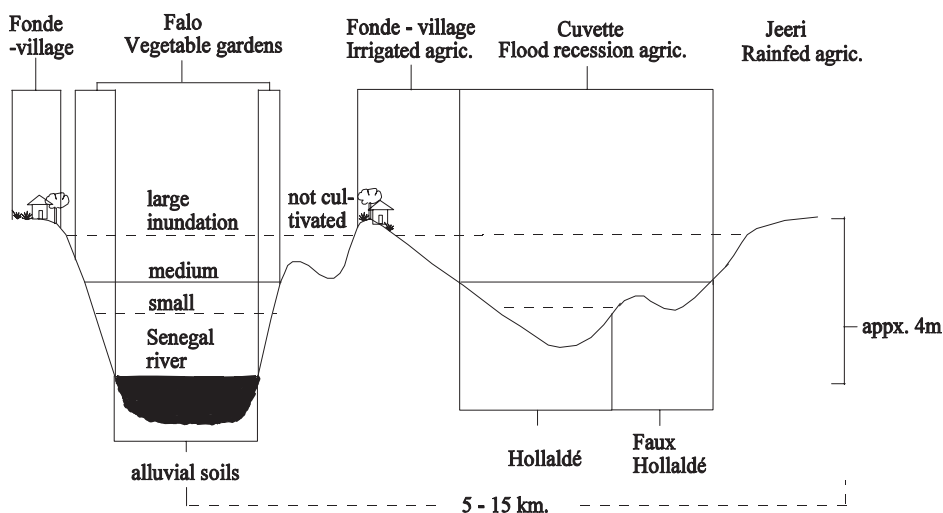


Figure 3: Land use and soil types of the middle/lower Senegal River Valley. Source: modified from Black & Sessay (1997), Euroconsult/RIN (1990), and Seguis, (1990).

Soil type	Characteristics	Cultivated crops
<i>Falo</i>	Silty alluvial and deep soils of high fertility since they are flooded every year and fertile sediments deposited.	Vegetable gardens.
<i>Fondé</i>	Texture is silty to sandy with 70% sand, 30% clay and a moderate water holding capacity. The sandy surface is easy erodible but easy to cultivate with high infiltration rates from 10-15 cm/hour.	Feasible for irrigated agricultural development often cultivating rice and onions when the soils occur along the river.
<i>Hollaldé</i>	Usually a dark brown soil with large amounts of clay 60% (vertisols in USDA Soil Taxonomy). It consist of alluvial sediments that are deposited by receding waters and have a high water holding capacity. It is flooded for a longer period in most years.	Flood recession agriculture is practised on the Hollaldé soils cultivating mainly sorghum, millet, beans, and melons.
<i>Faux Hollaldé</i>	Soils with a variable clay content, between 30-60%.	Used for flood recession agriculture. The soil is of marginal importance in years of low flood.

Table 1: Main soil types of the lower and middle Senegal River Valley. Based on Euroconsult/RIN (1990) and Tabor (1993).

The inter- and intra annual variability in water supply made it necessary for farmers to focus on risk minimization instead of production maximization, and most farmers not only practiced flood recession agriculture but also engaged in rain-fed farming in the jeeri. The farmers from Diatar used to walk 30 km from the village to the jeeri to reach their rain-fed fields. Most households owned a few animals which supplemented the household subsistence. The risk-minimising strategy of the farmers was in no way unique. The fishermen in N'Gaolé also practiced some agriculture besides their fishing activities, and the agro-pastoralists of Goumel, when located in the jeeri, also cultivated minor areas within the flood plain. The drought of the 1970s and 1980s caused a decline in flood recession agriculture, a termination of rain-fed farming in large areas, and a decline in vegetation cover when the herds started to return earlier to the valley and to stay longer (Moris & Thom, 1990; Euroconsult/RIN, 1990). The pressure on flood plain resources was further increased by the introduction of irrigated farming in the late 1970s and in the 1980s. The construction of large irrigated fields and dikes along the river occupied recession farm land and made it difficult for herds to access drinking water.

Land use of today

The irrigated farming system was introduced into all three

investigated villages in the beginning of the 1980s under strict control and managed by the state through SAED (Société d'Aménagement et d'Exploitation des terres du Delta du fleuve Sénégal et des vallées du fleuve Sénégal et de la Faleme). SAED supplied the villages with the necessary machinery, know-how, credit and marketing services (Crousse et al., 1991; Block, 1993). Today pump based irrigated cultivation using chemical fertilizers, herbicides and insecticides exists alongside the flood recession agriculture which is based on natural irrigation and natural fertilization. Recession farming is practiced whenever the inundations allow for it. The majority of the households in N'Gaolé and Goumel practice both irrigated and flood recession agriculture. A small number of households in N'Gaolé still practice fishing as their main occupation. In Diatar the limited inundations have led to the domination of irrigation farming on the greater part of the agricultural area belonging to the village and it has not been possible to practice recession farming since 1988. Rain fed cultivation of the jeeri is not practiced by farmers in any of the investigated villages due to the decline in rainfall and the location of the jeeri fields far from the villages as well as competition over labour resources from irrigated farming. There are though a few small rain fed fields at Goumel. During the investigated period these fields did not yield any measurable output to the Goumel

Crop	Labour Productivity (FCFA/h)	Labour Productivity (kJ/h)	Net income per area (FCFA/ha)	Net income per farming season (FCFA)
Sorghum	17 (62)	2.500 (9.900)	17.400	35.000 ¹⁾
Rice	300	50.200	328.400	124.000
Onion	474	-	233.100	130.500

Table 2: Average productivity and income related parameters from the harvest of 1997-1998. FCFA= Senegalese currency. () excluding the labour input used for guarding. Preliminary expenses regarding the irrigated farming system are not included. ¹⁾ The net income per farming season of sorghum when receiving normal yields of 400-700 kg/ha is 73 000-128 000 FCA.

farmers. In general the agricultural activities practiced in the investigated villages, can be described as a mixture between a) commercial irrigated onion farming and b) subsistence farming cultivating irrigated rice and c) recession farming of inter-cropping sorghum, beans and melons in the cuvette. The sorghum is planted along with the beans and melons when the inundation recedes from the cuvette often starting in November. The Sorghum is harvested during a one month period, starting 3½ months after sowing i.e. in the middle or end of February. The harvest of beans and melons is an ongoing process which lasts from the maturity of the first fruits until only marginal yields are collected. During the years with a large harvest from the cuvette, a limited part is sold at the market in Podor. Rice is cultivated during two different seasons; in the dry and hot season from March to June, or at the end of the rainy season from July to the beginning of November. A total of 65 % of the rice farmers did not commercialize any part of their production. Of the farmers who did sell part of their rice, only 30 % of their total production was sold. Thus, the majority of the rice production is used for subsistence. The onion season lasts four months from November to March and the major part of the harvest is sold to cover input expenditures for the onion and rice production. Chemical fertilizers, herbicides and insecticides are used for the irrigated crops. The extent of the use of high yielding seed varieties (HYV) is unknown but probably rather limited due to high costs. No chemical inputs are used in the flood recession farming system.

Results and discussion

Productivity of flood recession agriculture

Before discussing and comparing the productivity and yields of flood recession farming compared to that of irrigated farming, it is important to stress that yields recorded during the fieldwork are based on a period of

very limited flooding. This is evident when comparing the historic river levels at Podor with river levels during the investigated period. Yields from recession farming therefore are likely to be underestimated if compared to the years of normal inundations, as discussed below.

Table 2 compares the output from the irrigated farming system with that of the recession farming system as recorded during the fieldwork. It can be seen that the labour productivity and the net income per season of the irrigated crops far exceeded that of flood recession farming. However, these figures are prone to large variations depending on input and output prices, the yearly variation in the extent of the flooding, the possible attacks of pests and diseases and the labour available of the households.

Sorghum is the only crop taken into consideration when discussing the flood recession farming system, as the recorded harvest of beans and melons was insignificant. However, since the sorghum yield observed during the fieldwork was described as being very limited and well below normal yield, an average of 178 kg per hectare, the importance of the flood recession farming in the years of average or large inundations is therefore underestimated as well as the net income as presented in Table 2. If the observed sorghum yields were to be exchanged with the expected average local yields as noted in regional reports, 400-700 kg per hectare (FED, 1996), and still using the same size of the cultivated area, the average net income from a farming season of sorghum, excluding beans and melons, account for 73 000-128 000 FCFA (Senegalese currency). This implies that in years of satisfactory inundations the possible net income from the flood recession farming system is likely to equal the net income of each of the irrigated crops. Not only might the production per area increase during satisfactory inundations as the soil moisture is retained for a longer period, but the cultivated area also increases allowing for a larger total production. Therefore, the calculated net income from a season of satisfactory inundations is likely to increase further.

Sorghum	S400	S700	Rice+Sorghum	Rice+S400	Rice+S700
10%	27%	48%	49%	69%	86%

Table 3. Yearly energy supply of the households covered by the rice and sorghum harvest from 1997-1998. S400 = assuming sorghum yields of 400 kg/ha. S700 = assuming sorghum yields of 700 kg/ha.

Household energy requirements

If the statistics about the energy expenditures from the two farming systems had been available, a comparison would have shown that the flood recession farming system receives exceptionally higher net returns on energy expenditures, especially compared to the input intensive irrigated farming system. This is because no inputs other than labour and land are needed (Park, 1992). Table 3 shows the importance of the subsistence crops, sorghum and rice, in meeting the yearly energy requirements in the households of the interviewed farmers who practice both irrigated and recession farming.

From the table it can be seen that in 1997 - 1998 the sorghum harvest supplied a minor but very important contribution to the household subsistence due to the fact that their energy requirements are hardly covered by the irrigation farming alone. This makes every contribution to the household subsistence significant, no matter the size. However, even when receiving normal returns from the recession farming the total energy requirements provided from this agricultural production were still 14 - 31 % less than household energy requirements.

The flood recession area is limited to that of the cuvette and therefore cannot be further expanded, whereas the irrigated area or the irrigated farming frequency is likely to increase in the future. Therefore, the irrigated farming system has the potential for significantly increasing the energy production of the household which is necessary to feed an increasing population but also to improve the general conditions of life in the investigated villages. Furthermore, if inundations were to remain limited, the energy supplied by the sorghum harvest can relatively easily be substituted by an overall increase in the irrigation production, although this is not a free choice for the individual farmer but depends strongly upon economic relations and access to land. As will be discussed below, a reduction of the recession farming is not necessarily a sound solution for solving the problem of meeting the daily energy requirements. Furthermore, since both rice and sorghum are energy-rich but not specifically high value crops, they are not likely to be substituted by crops containing larger amounts of energy through market-exchange. They are very suitable crops for resource limited

farmers. Finally, the household energy supply is still supported by melons and beans cultivated in the recession fields, which in some years yields large amounts, and on a smaller scale by vegetables cultivated in riverside gardens.

Beyond economic rationality

The farmers have to decide which products they want to produce from the available resources. In the case of the investigated villages this does not leave many possibilities. Any capital invested in agriculture is invested in irrigated farming. The allocation of land and labour is divided between the irrigation farming and the cultivation of rice or onions, or the flood recession farming and the cultivation of sorghum, beans and melons. The choice of resource allocation is not necessarily free due to the organization of the irrigated farming system in the villages and the individual resource access (Larsen, 1999). However, agricultural tasks in the irrigated fields are sometimes interrupted and postponed due to the individual preferences of some of the farmers to allocate labour to field preparation or harvest of the flood recession fields, thereby possibly reducing the size of the irrigated production. It has been discussed above that within the household perspective the recession production is less productive both in terms of yields, economy and energy content, and therefore this preference might seem irrational. However, recession agriculture yields sorghum, beans and melons between the normal harvest periods of rice and onions at times when other agricultural contributions to the household subsistence are limited. Any loss in the production of rice or onions due to allocation of labour to the recession fields might therefore instead ensure a greater contribution to the day to day energy requirements of the household. This is especially important in villages without storage facilities, such as N'Gaol , where crops cannot be stored for longer periods, and where even a large harvest is not necessarily capable of covering the daily energy requirements of a family until the next harvest. Furthermore, no capital inputs are required at the start of the recession farming seasons and only the inundation dynamics, and the availability of labour, determine when and where to start the

farming season preparations. The mono-cropping of the irrigated fields increases the risk of crop failure due to insect attacks and plant diseases, whereas the inter cropping of melons and beans in the cuvette are likely to produce some yield, even if the sorghum harvest is limited. When the farmers were asked which farming system they preferred to practice, and assuming that inundations would supply a large flood, they all preferred flood recession farming. When asked about the disadvantages of the flood recession farming system none of the farmers could mention any. The farmers pointed out that the recession farming required no capital input and less labour compared to irrigated farming. It was further mentioned that recession agriculture represented a higher degree of individualism when compared to the strict agricultural organization on the village level that controlled the economic and labour investments of the irrigated farming system (Larsen, 1999).

Limitations of the flood recession farming

It is necessary to investigate the limitations to area and production of recession farming when discussing historical changes of the farming potential as well as the future of flood recession agriculture. In the investigated villages changes of the farming potential relates mainly to two factors. Firstly, to the changes in water dynamics caused by declining precipitation and the construction of the Manantali dam and, secondly, the introduction of irrigation farming.

Influence on recession farming of the reduced precipitation and the construction of the Manantali dam

The influence of reduced precipitation on the volume of the water flow in the Senegal river is illustrated by the downward trend of Figure 2. Knowing the close correlation between the water flow at Bakel and the size of the inundations around Podor, Figure 2 indicates that the limited precipitation has a negative influence on the size of the river valley inundations.

The Manantali dam is another factor which has influenced the possibility of practicing flood recession agriculture in the investigated villages. In general the impact of a dam on downstream flow patterns depends upon the seasonal flow regime of the river and operational procedures of the dam. The OMVS, who manages the Manantali dam, has not disguised the fact that the main purpose of the dam is not to support the recession farmers but to

produce hydroelectricity and then to ensure water availability for irrigation and navigation. If a dam is to favor all year round irrigation and navigation, moderate variations in the yearly flow regime are preferable. This implies that the reservoir lake should be filled in the wet season so that rivers with a short water supply season and high magnitude flow, such as the Senegal River, can supply yearly moderate flows and some residual flows during times of high water demands (Adams, 1990). Hydroelectricity dams are designed to have a constant flow through their turbines, and therefore tend to have a similar effect on discharge patterns (Adams, 1990). It is difficult to coordinate this management strategy with the needs of the recession farmers. The uncertainty and new variation in river flows, caused by the dam and the different management practices, makes it difficult for the flood recession farmers to adjust agricultural practices with expected flooding. Peaks in power demand may affect flood flows during the year, floods, if released at periods outside the natural inundation seasons, might have significant negative impact on downstream recession agriculture. In 1994 the Manantali dam released two successive floods without informing the downstream recession farmers. The second flood inundated the newly planted fields which resulted in a massive crop failure. If the dam were to control flooding, and thereby give the possibility of supporting flood recession agriculture, water should be stored over time in order for the dam manager to imitate natural flows, while controlling the water release in times of flood conditions.

It was expected that the management of the Manantali dam would create a reduction in the temporal and spatial inundations in the Senegal River Valley and causing a decline in flood recession agriculture. This was investigated in a study by Rasmussen et al. (1999). By studying the natural and dam affected water flows at Bakel between 1987 and 1996 it was concluded that the operation procedures of the Manantali dam in three out of ten years have caused a significant reduction of the total volume of the inundation or reduced peak flows at Bakel to a level below the critical limit thereby preventing a successful flooding of the valley. Furthermore, it was concluded that it did not seem as if the dam managers had supplemented the flood in years of limited water flow, even though the dam reservoir had been full. Therefore, the decline in inundations, and thus the reduced potential for flood recession agriculture in the investigated villages during the last decades, is to be attributed not only to the decline in precipitation but also to the management of the Manantali dam.

Furthermore, a decrease in spatial or temporal inunda-

tions and/or a decrease in the sediment content of the river water may cause changes in flood plain fertility and affect flood plain farming (Adams, 1992). The fine sediments of the river water often carry organic and inorganic nutrients which are deposited in the flood plains when inundated. A decrease in the nutrient deposits on the flood plain, either due to deposition of fine sediments in the Manantali reservoir or due to the reduced inundations, may therefore have severe consequences for the flood recession farming system where sediment deposits, and sometimes animal manure, are the only fertilization of the soil. However, no studies have yet been performed to measure such effects.

Local effects on recession farming in the investigated villages

The local effects of the reduced precipitation and the Manantali dam on the flood recession agriculture in the investigated villages depends heavily on the elevation of the local farmland in relation to the elevation of the river bed. An average flood will only just inundate the land around Podor (ENDA, 1986). This implies that even minor changes in the water flow can have a serious influence on flood recession farming in the investigated villages. Furthermore, this sensitivity to the level of the water flow can be expected to create large local agricultural differences, as the local topography determines the threshold above which the river has to rise before water enters the flood plain channels which carry the river water onto the low-lying cuvettes.

Only few observations exist on the relationship between the size of the flood and the flooded area. However, the extent and duration of the inundation are most relevant factors when discussing flood recession agriculture. A topographical transect between the Senegal river and the river branch Doué, approximately four kilometres east of Diatar, shows that the lowest level of the cuvette is approximately 4 metres IGN (Seguis, 1990). When this is compared with maximum historical river levels at Podor from 1903 to 1969, the river level has been below the level of the cuvette, which may have caused severe difficulties in flood recession agriculture in 6 out of 67 years. From 1970 until 1986 the river level was below the level of the cuvette in 13 out of 17 years, whereas it has been below this level in 8 out of 11 years between 1987-1997. The interviewed farmers in Diatar confirmed that the inundations have never regained their pre-drought dimensions. This explains why irrigated fields have been constructed on the greater part of the former productive recession land in Diatar.

The level of the cuvette farmed by farmers from N'-Gaolé and Goumel is lower than that of Diatar. Therefore, farmers in these villages have been able to maintain flood recession agriculture until today, yet at a reduced scale. Based on comparisons between river levels from 1995-1997 and the farming frequency of the interviewed farmers from N'-Gaolé and Goumel, a local estimate of the level of the cuvette can be given. In 1995 and 1997 when the maximum river level at Podor was respectively 4,75 metres and 3,85 metres IGN all the interviewed farmers cultivated their fields on the cuvette, whereas only one of the interviewed farmers was able to cultivate in 1996 when the maximum river level was 3,26 metres IGN. On this basis it can be estimated that the majority of the recession land is probably located below 3,85 m IGN, whereas only limited parts of the cuvette are located below 3,26 m IGN. The river level has been below 3,26 meters in 1 out of 67 years from 1903-1969. From 1970-1986 this happened in 4 out of 17 years and from 1987-1997 it happened in 3 out of 11 years. The elevation of the cuvette, might be confirmed or disproved through further studies by the ongoing project "Integrated Earth Observation Data in Distributed Agro-hydrological Models", a project working on a digital elevation model of the cuvette (Sandholt et al., 1999).

There seems to be a great annual difference between the size of the inundation and the part of the flooded area being cultivated. Explanations for this can be many but mainly relate to the yearly differences in the size of the potential agricultural area. A large flood may inundate areas not suitable for cultivation and thus result in a low percentage of cultivated land compared to the size of the flood. On the other hand a small inundation may tempt the farmer to cultivate agriculturally marginal areas, hoping for some output although of a very limited size. Finally, competition from other elements of the livelihood strategies such as trade, or competition from irrigated and rain fed agriculture, especially on labour resources, could lead to a decrease of the cultivated area, despite the dimensions of the inundations, as will be discussed below.

The impact of irrigated agriculture on flood recession farming

Regarding the influence of the irrigated farming system on flood recession agriculture, several issues attract interest like the construction of dikes along the river following the building of the irrigated fields. The dikes reduced the width of the flood plain channels where water from the main rivers (Doué and Senegal) is led onto the cuvette.

This may have had a serious impact on the accessibility of river water flooding onto the recession fields but data from the fieldwork does not allow for any conclusions on this subject.

Inputs into the flood recession farming system are land, labour, water and solar energy. The solar energy is plentiful and there is no conflict of interest at the village level over the allocation of water between recession and irrigated farming. The water for irrigation is pumped from the river and the availability of water in the cuvette depends on natural river dynamics and to some degree on the management of the Manantali dam. The only controlled inputs into the flood recession farming system at the village level, as it is practised today, are land and labour. When irrigated farming was first introduced, farmers gave up the flood recession farmland located on the higher Fondé soils close to the village and the river, to leave space for the construction of irrigated fields, see Figure 3. This land had become marginal for flood recession farming due to limited inundations. The land however was suited for irrigated farming as the water pumps for irrigating the new constructed fields had to be located close to the river. The farmers who gave up recession land, although of marginal importance at the time, were ensured a number of plots depending on the size of their former recession land in the new irrigated fields. Until today the irrigated fields have only been inundated a few times since their construction and at present they do not occupy productive flood recession farmland. To what degree this is caused by the location of the fields on the higher grounds close to the river, the limited inundations or by the hindrance of river water entering the cuvettes, is unknown. If the river dynamics were to change in the fu-

ture or new agricultural techniques introduced into the recession farming the irrigated fields could, in principle, constitute a potential future flood recession area.

Labour is the second controllable input into the recession farming system which might have decreased due to the introduction of irrigated agriculture. Figure 4 illustrates the accumulated average monthly labour input of the interviewed farmers during the farming season. From the figure it can be seen that the highest average labour input coincides with the start and end of the farming season. Furthermore it can be seen, that except from the month of February, the simultaneous cultivation of irrigated onions and flood recession sorghum imposes no specific labour shortage. However, the figure illustrates the dependency of the agricultural calendar on the timing of the inundations as an early inundation will reduce the risk of labour shortage during the irrigated onion harvest in February/March, but will coincide with the harvest of the irrigated rice in October. Conversely, a late inundation may create labour shortages in February and March for the onion harvest, and therefore a possible delay of the following rice season.

The labour input in February of 138-157 hours per week might result in labour shortage in at least four out of 11 households, when comparing the labour input with the number of male farmers in the interviewed households. However, the women participate in the start and end of the farming seasons, which correspond to the period of maximum labour demands. This lessens the risk of labour shortage into the periods of maximum labour demands. Furthermore, guarding the sorghum on the recession fields against bird attack constitute 72 % of the total labour input used for recession farming. The task is for a large part performed by children and elders. Thus, even though guarding the recession fields against bird attack is a very time consuming task, it does not affect the labour demand on farmers of the interviewed households. To give a more realistic estimation of whether there is labour shortage in the interviewed households, the labour inputs of children and elders used for guarding the fields in February are excluded. Then the total labour input decreases to that of two persons, 79-96 hours per week. Of course the labour input used by children and elders for guarding the sorghum cannot be fully excluded, but it nevertheless suggests that the simultaneous cultivation of recession sorghum and irrigated onion is not affected by labour shortage. It has to be stressed, though, that the labour figures are based on a limited number of interviews and might vary significantly between farmers and years. Fur-

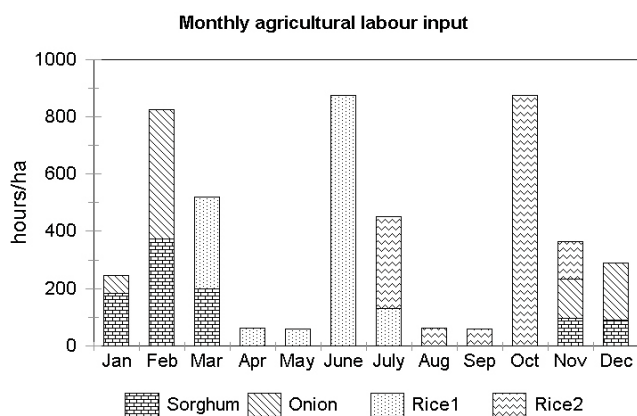


Figure 4: Monthly labour input into flood recession- and irrigated agriculture. Sorghum is cultivated in the cuvette whereas onion and rice is cultivated in the irrigated fields.

thermore, the reported sorghum harvest used for the calculations on labour demands is very limited. Therefore the labour inputs from November to February are likely to be underestimated compared to the labour demands of a normal recession harvest due to the relatively limited amount of work performed in the recession fields during the investigated period.

Future alternatives for flood recession agriculture

Despite the importance of the flood recession production and the high net returns to the energy expenditures it is still obvious that flood recession farming yields less, measured in kilograms and FCFA, than the irrigated farming system. When discussing future perspectives for recession farming one can therefore ask why OMVS should ensure a yearly inundation of the river valley making it possible to preserve the flood recession farming system? Why not, on the local level, transform the cuvettes to irrigated fields resulting in higher yields and with the capability to feed a larger population? On the external level this would mean that OMVS would not have to worry about how the dam management could affect the production of recession crops and the consequent reduction of hydroelectricity. On the other hand, if flood recession farming is so important, it could be suggested to increase, or even change the recession farming practice on the local level by applying chemical inputs, use of high yielding seed varieties and irrigation techniques? The final question is how the implementation of the hydroelectricity scheme at the Manantali dam will affect the future water management of the Senegal River and thus whether flood recession farming will survive in the future.

Why preserve the annual flood and flood recession agriculture?

The flood recession farming system supplies an important input to the household subsistence and provides the households with sorghum, beans and melons in months of limited food supply, especially in January and February. Given that the last rice is harvested in June-July, and since the profits from the onions are not collected until March, these crops might be of major importance to the daily energy requirements of the farming households. However, it was demonstrated that the food supply, and thus the survival of the household, is based on diversifying the production towards different crop types, farming systems and land use practices, which viewed individually only with

difficulty maintain a constant and sufficient food supply. The loss of inundation, by the planned stabilisation of the river flow, will not only affect recession farming. It will also affect the regeneration of wood resources and cause a decline of grazing lands, and leave only limited pasture for the animals to feed on, reduce the fuel wood supply for the household and will decrease the replenishment of shallow and deep aquifers in the valley. A result of the decline in recession agriculture is that pressure on the capital intensive irrigated farming system supporting the household subsistence will increase. This creates a rising economic demand necessary for the expansion of the cultivated area or for an intensification of the production. At the moment this capital is not available to the households and will therefore have to be generated through wage labour elsewhere. An agricultural system based on mono-cropped irrigated farming would further increase the risk of periods with insufficient food supplies, as a crop failure leaves only few other opportunities. In a wider perspective the development of irrigated agriculture will probably be able to supply the household subsistence throughout the year, but this will not prevent the negative effect on the flood plain environment.

Increase in the flood recession production

Findings from this study have shown that the availability of water is the major limiting factor to the size and extent of the flood recession farming. Studies have been carried out concerning the possibility for constructing a type of small sluice, which placed in the flood plain channels can control the size and duration of the flood plain inundations (Salem-Murdock et al., 1993). Another solution could be to channel the seasonal drainage water from the irrigated fields through channels onto the cuvette and thus provide irrigation water for recession farming. This, though, requires proper management practices, ensuring that salts are flushed away, but would allow for the nutrient rich water from the irrigated fields to fertilize the cuvettes during and between flood recession farming seasons. This might further increase the farming frequency of the cuvette, if the irrigation water could sustain cultivation of additional crops between the present farming seasons (Larsen, 1999). Finally, some fertilizer experiments have been undertaken to improve crop yields of the recession agriculture, but positive results of applying N and P have only been attained under experimental conditions (Salem-Murdock et al., 1993). However, all the above incentives to improve the flood recession farming system depend on large amounts of capital input. An analysis of the irrigated

<i>Energy losses by supplementing the natural flood</i>	Recession cultivated area (ha)	Cost/ha (FCFA/ha)
Flood: $7,5 \times 10^9 \text{ m}^3$	50.000	53.600
Flood: $8,5 \times 10^9 \text{ m}^3$	75.000	45.730
Flood: $10,0 \times 10^9 \text{ m}^3$	100.000	46.300

Table 4: Assessment of the energy loss of OMVS when supporting an artificial flood. Modified from OMVS (1987).

farming system in the investigated villages has shown that the input costs of especially chemical inputs, are already one of the major limiting factors in the size of the irrigated production and that further purchase is not affordable by the local farmers (Larsen, 1999). The use of chemical inputs in the recession agriculture is not likely to be economically feasible, unless these additions give very high returns. Furthermore, it is not likely that any capital will be used for boosting the flood recession production in various ways if the factor of uncertainty is not eliminated. To eliminate the uncertainty of the size of the river valley inundations there has to be a political incentive to preserve the system which can make OMVS support a stable and annual flood. This has never been a part of the management plan for the Manantali dam and the general interest for this idea among the member states of the OMVS is most likely limited. Of the three member states, Mali is the one located upstream in the river valley and, therefore, has only limited access to flood plain resources. Mali is mainly interested in a river-based opening from Mali to the Atlantic Ocean and in the royalties which can be obtained from the sale of electricity, supplied from a power line going from the dam site to Bamako (Horowitz & Salem-Murdock, 1993). Less than one third of the potential flood recession land of the river valley is located in Mauritania. The main policies of the Mauritanian government concerning the river valley have so far been to extend the irrigated agriculture (Horowitz & Salem-Murdock, 1993). Therefore, the political impetus to support and top up the natural flood when necessary, is limited unless it does not conflict with the primary objective of the dam, which is to produce hydroelectricity.

Future perspectives in the management of the Manantali dam

It is relevant to address the perspectives in the management of the Manantali dam for supporting river valley inundations when discussing the future of the flood recession farming system. It has been calculated how many years it would have been necessary to supplement the natural river flows with water from the dam reservoir to en-

sure a minor inundation of the river valley allowing for cultivation of 50.000 ha flood recession land (Salem-Murdock et al., 1994). This would have been necessary in the 19 years from 1904-1984, of which 11 years were the drought period of 1970-1984 (Rasmussen et al., 1999). Since the main purpose of the dam is to produce hydroelectricity, it is interesting to briefly investigate to what extent the dam could supplement river valley inundations when necessary, while at the same time producing in average 800-900 GWh, which is the amount of energy demanded by the OMVS. Only in the years 1913, 1977 and 1979-84, (or 9,9 % of the period), would the Manantali reservoir not have been filled by the end of October, while at the same time being able to ensure the cultivation of 50.000 ha flood recession land in the valley (Salem-Murdock et al., 1994). Thus, it would only be necessary to decrease the energy production in August and September during a few years to allow for a minor inundation in the valley. If the current hydrological conditions were to continue and if the dam was managed, so as to support river valley inundations by supplementing natural flows when necessary, the energy production would decrease to approximately 600 GWh during August and September (Gibb et al., 1987). It therefore, seems that the future of the flood recession agriculture depends on the political will, in the years of limited natural flows, accepting a reduction in the maximum energy supply during two months for the advantage of cultivating flood recession farming.

Table 4 illustrates the loss of the OMVS in FCFA/ha when supporting an artificial flood of different dimensions. If this is compared to the net benefit from flood recession farming as illustrated in Table 5, it can be seen that a higher net benefit might be generated by using the water for supplementing the natural flood rather than producing hydroelectricity. This comparison should in principle include the value of all crops cultivated in the flood recession fields, as well as the value of other flood plain resources depending on the inundations. However, whereas the value from the production of hydroelectricity is shared among the three member states of OMVS, the agricultural

Flood recession agric.	This study	OMVS (1987) ^a	Salem-Murdock et al (1993)	Normal yields
Yield (kg/ha)	178	600	?	400-700
Net benefit (FCFA/ha)	17.400	34.000	36.000	39.200-68.600

Table 5: Comparison of output from the flood recession farming system between three studies. ^{a)} The calculations include a cost on inputs of 22.600 FCFA/ha.

value generated from the inundation of the flood plain is mainly obtained by Senegalese and Mauritanian farmers and the land users of the flood plain. All these arguments should be kept in mind when comparing costs and benefits in the future water management planning for the Senegal River.

Conclusion

The flood recession farming system in the investigated villages is based on natural irrigation and fertilization of the flood plain where sorghum, beans and melons are cultivated on the remaining soil moisture of the receding flood. The system is characterised by very high net returns to energy since the only inputs are land and labour. The drought of the 1970's and 1980's as well as the construction of the Manantali dam in 1987 caused a reduction of the river valley inundations. This decreased the size and possibly the fertility of the recession cultivated area. The introduction of irrigated farming into the valley during the 1980's led to the expansion of pump based irrigated farming on the higher grounds close to the river that had become marginal for recession farming.

Results from the study are affected by the limited inundations during the investigated period which caused an underestimation of the output from the recession farming when compared to the normal yields. It can, however, be concluded that the major importance of the flood recession farming to farmers in the investigated villages is the sorghum, beans and melons supplement to the household subsistence especially during months where other contributions to the household subsistence are limited. However, the system is not able to supply a stable contribution to the household subsistence and the yearly differences in the extent of the inundations make the size of the contribution very unpredictable. If agricultural practices of recession farming are not further developed, the importance of the farming system is likely to decrease as local population figures rise and irrigated agriculture is further developed. Since farmers cannot control the water for recession

farming, there is no incentive for the farmers to invest in the development of the farming system. The future of flood recession agriculture will therefore primarily depend on the willingness of OMVS to supplement the natural flood in August and September and thereby ensure a yearly flood. This will reduce the maximum hydroelectricity production in years of limited natural flows even though the findings suggest that it is still possible to attain a rather large energy production, while at the same time supporting the downstream flood recession agriculture. Furthermore, the study shows that using the water for recession farming might be just as economically feasible as preserving the water for hydroelectricity production. However, the benefits of the agricultural production are not distributed equally among Senegal, Mauritania and Mali. The final choice of allocation of water resources therefore is between an increased production and secure supply of hydroelectricity to a large urban population and industry, compared to the flood recession production which at present is of importance to the subsistence of a large agricultural population in the Senegal River Valley.

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L'agriculture de décrue dans la vallée du fleuve Sénégal.

Nina Larsen Saarnak

Résumé

Cet article explore la dynamique des systèmes agricoles, ainsi que l'importance et l'avenir des faibles rendements de l'agriculture de décrue telle que pratiquée dans la Vallée du Fleuve Sénégal. Cette analyse est faite en relation avec l'introduction de l'agriculture irriguée au niveau des villages de la vallée, mais aussi en rapport avec les modifications hydrologiques du Fleuve Sénégal causées par la construction du Barrage de Manantali et l'avènement des années de sécheresse entre les années 1970 et 1980. Les données utilisées pour ce travail ont été collectées pendant une mission de terrain de trois mois dans trois villages de la zone de Podor (Sénégal). Les informations obtenues pendant cette mission de terrain concernent les aspects physiques et écologiques des systèmes agricoles de décrue. Elles ont été collectées en utilisant des entretiens semi-structurés au niveau de ménages et de groupes d'individus composés des anciens du village ou des promoteurs agricoles. Au niveau national, des entretiens ont été menés auprès des autorités responsables des aménagements hydriques et agricoles.

Le système agricole de décrue est basé sur l'irrigation et la fertilisation naturelles des plaines alluviales. Le sorgho, le haricot et le melon sont cultivés à partir de l'humidité résiduelle du sol après les inondations annuelles de la vallée pendant les mois d'Août et de Septembre. L'agriculture de décrue ne requiert pas d'intrants contrôlables autre que l'accès à la terre et à la main d'œuvre et présente ainsi un grand bénéfice net en termes de coût énergétique. L'étude montre cependant que le rendement de la main d'œuvre ainsi que le revenu net de l'agriculture irriguée, exigeante en intrants, est de loin plus important que ceux de l'agriculture de décrue. Cependant, la production de l'agriculture de décrue est très importante pour la subsistance des ménages dont les besoins alimentaires ne peuvent être satisfaits par la seule agriculture irriguée. L'agriculture de décrue peut ainsi supporter la subsistance des foyers pendant plusieurs mois au moment où les autres sources d'approvisionnement de la famille sont limitées. En outre, la production de la culture de décrue était très affectée par la faiblesse des crues pendant la période d'étude.

Le contrôle de débit au Barrage de Manantali au Mali ainsi que les variations pluviométriques dans la partie du

haut bassin du fleuve entraînent des fluctuations annuelles de la crue affectant la production de la culture de décrue. Puisque l'agriculteur n'a pas de contrôle sur l'inondation des champs de vallée, il n'est pas motivé à s'investir dans la promotion de l'agriculture de décrue. Si le système n'est pas amélioré, le potentiel futur de l'agriculture de décrue va inévitablement diminuer au moment où la population et la demande en produits de subsistance augmentent et l'agriculture irriguée fortifiée. Par conséquent, l'avenir de la culture de décrue dépend dans une large mesure de la volonté des autorités du Barrage à assurer une inondation annuelle et stable des champs de décrue pendant les années à faible crue. Ceci pourra mettre fin à l'insécurité de la disponibilité en eau et justifier un effort d'investissement supplémentaire pour le développement des pratiques agricoles traditionnelles.

Mots-Clefs

Agriculture de décrue, Barrage de Manantali, Vallée du Fleuve Sénégal.

References

- Adams, W. M. (1990): Green Development - environment and sustainability in the third world. London, Routledge.
- Adams, W. M. (1992): Wasting the rain - Rivers, people and planning in Africa. London, Earthscan Publications Ltd..
- Barrow, C. (1987): Water Resources and Agricultural Development in the Tropics. New York, Longman Scientific & Technical.
- Black, R. & Sessay, M. F. (1997): Refugees, land cover, and environmental change in the Senegal River Valley. *GeoJournal* 41(1):55-67.
- Block, P. C. (1993): An Egalitarian Development Project in a Stratified Society: Who Ends Up With the Land. Pp. 222-243 in: Basset, T. J. & Crummy, D. E. (ed.): Land in African Agrarian Systems. The University of Wisconsin Press.
- Crousse, B., Mathieu, P. and Seck, S. M. (1991): La vallée du fleuve Sénégal - Évaluation et perspectives d'une décennie d'aménagements. Paris, Karthala.
- Darkoh, M. B. K. (1992): African River Basins at Risk. Pp. 1-12 in: Darkoh, M. B. K. (ed.): African River Basins and Dryland Crises. Uppsala, Reprocentralen.
- ENDA & Ministère de la Coopération (1986): Enjeux de l'après-barrage - vallée du Sénégal. In: Engelhard, P. &

- Abdullah, T. B. (ed.): ENDA & Ministère de la Coopération. France.
- Euroconsult/RIN (1990): Profile de l'Environnement de la Vallée de Fleuve Sénégal. Paris, Euroconsult & Institut National de Recherche pour la Conservation de la Nature (RIN).
- FED (1996): Plan Proposé Pour la Relance du GIE N'-Gawlé 1996-97. Podor, FED.
- Gibb, A. & Partners (1987): Study of the management of the OMVS common works. Summary Report. Paris, Electricite de France Internationale, Euroconsult.
- Gibb, A. & Partners (1990): Plan Directeur de Developpement Intégré pour la Rive Gauche de la Vallée du Fleuve Sénégal - Document Definitif - Annex A. Paris, Euroconsult.
- Horowitz, M. & Salem-Murdock, M. (1993): Development-Induced Food Insecurity in the Middle Senegal Valley. *GeoJournal* 30(2): 179-184.
- Larsen, N. (1999): Agricultural Development and Dynamics in the Senegal River Valley - a case study from three villages in the Podor region. Master Thesis from Institute of Geography, University of Copenhagen.
- LeMarquand, D. G. & Iwra, M. (1990): International development of the Senegal River. *Water International* 15(4): 223-230.
- Lewis, L. A. & Berry, L. (1988): African Environments and Resources. London, Unwin Hyman.
- Moris, J. R. & Thom, D. J. (1990): Irrigation Development in Africa - Lessons of Experience. *Studies in Water Policy and Management* 14, Westview Press.
- Mounier, F. (1985): The Senegal River Scheme: Development for Whom. Pp. 109-111 in: Goldsmith, E. & Hildyard, N. (ed.): *The Social and Environmental Effects of Large Dams. Volume 2, Case Studies*. Wadebridge Ecological Centre.
- OMVS (1979): *Fleuve Senegal*. St. Louis (Senegal), Centre du Documentation OMVS.
- Park, T. K. (1992): Early trends toward class stratification. Chaos, Common Property and Flood Recession Agriculture. *American Anthropologist* March: 90-117.
- Park, T. K. (1993): Risk and Tenure in Arid Lands - The Political Ecology of Development in the Senegal River Basin. Tuscon, The University of Arizona Press.
- Rasmussen, K., Larsen, N., Planchon, F., Andersen, J., Sandholt, I. & Christiansen, S. (1999): Agricultural systems and transnational water management in the Senegal River Basin, *Danish Journal of Geography* 99: 59-68.
- Sahli, M. A. (1992): African Dryland Crisis and the River Basins. Pp. 13-19 in: Darkoh, M. B. K. (ed.): *African river basins and dryland crises*. Uppsala, Reprocentralen.
- Sandholt, I., Andersen, J., Dybkjær, M., Lo, M., Rasmussen, J. C., Refsgaard, C. & Høgh-Jensen, K. (1999): Use of remote sensing data in distributed hydrological models: applications in the Senegal River Basin. *Geografisk Tidsskrift, Danish Journal of Geography* 99: 47-59.
- Salem Murdock, M., Niasse, M. & Magistro, J. (1994): *Les Barrages de la Controverse, Le cas de la Vallée du Fleuve Sénégal*. Paris, L'Harmattan.
- Salem-Murdock, M. & Niasse, M. (1993): Landuse, Labour Dynamics, and Household Production Strategies: The Senegal River Valley. Institute for Development Anthropology, IDA Working Paper No. 94. New York, Binghamton.
- Seguis, L. (1990): Note sur la propagation de la crue le long de l'Ile à Morfil et sur les inondations 1986 et 1988. Dakar, ORSTOM.
- Tabor, J. (1993): Soils of the lower, middle, and upper Senegal River Valley. Pp. 31-50 in Park, T. K.: *Risk and Tenure in Arid Lands - The Political Ecology of Development in the Senegal River Basin*. Tuscon, The University of Arizona Press.
- USDA (1994): *Keys to Soil Taxonomy*. United Department of Agriculture Soil Conservation Service. Washington, Pocahontas Press Inc.

