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Soil erosion in the West African Sahel: a review and an application of a "local political ecology" approach in South West Niger

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Abstract

A review of soil erosion research in the West African Sahel finds that there are insufficient data on which to base policy. This is largely because of the difficulties of measuring erosion and the other components of "soil life", and because of the highly spatially and temporarily variable natural and social environment of the Sahel. However, a "local political ecology" of soil erosion and new methodologies offer some hope of overcoming these problems. Nonetheless, a major knowledge gap will remain, about how rates of erosion are accommodated and appraised within very variable social and economic conditions. An example from recent field work in Niger shows that erosion is correlated with factors such as male migration, suggesting, in this case, that households with access to non-farm income adopt a risk-avoidance strategy in which soil erosion is accelerated incidentally. It is concluded that there needs to be more research into the relations between erosion and socio-economic factors, and clearer thinking about the meaning of sustainability as it refers to soil erosion in the Sahel.

Keywords: Soil erosion; Sahel; Agriculture; Local political ecology; Niger

1. Introduction

This paper assesses soil erosion research in the West African Sahel at a number of levels: through an historical review of research and by arguing for a local political ecology of soil erosion, illustrated by a case study from southwestern Niger.

Soil erosion in the Sahel has been studied since the 1930s. The history of intervention to conserve soil is almost as long, if not longer, for the colonial regimes pre-empted research with some large, technocratic conservation programmes. From about the early 1980s these efforts were deemed to have failed, and new programmes emphasised indigenous husbandry, built upon local knowledge, and sought participation by farmers. International policymaking, particularly the Desertification Convention in the 1990s, has institutionalised these tendencies. Yet, many authorities believe that participatory development has not been fully successful in tackling erosion (Scoones et al., 1996; Scoones and Toulmin, 1999).

We begin the paper by a review of research, which is in two parts. The first is of research into biophysical processes. We confine this to soil erosion, or more precisely, to the gross sediment budget and its effects on yield (which act mainly through the loss of available moisture (e.g. Mota et al., 1995)). The review avoids two closely related questions, which would open the debate too far for one paper. The first is soil conservation, which has a very large literature, and some recent reviews (Stocking, 1992; Trench and Batterbury, 1999; Mazzucato and Neimeijer, 2000). The second is the question of soil nutrient flux, which is reviewed by Breman et al. elsewhere in this collection. This section of our review reveals very large uncertainties, as have similar reviews for other parts of the world (e.g. Thompson et al., 1986; Ives and Messerli, 1989).

The second part of the review is of the social and economic associations of erosion. It builds on the work of Tiffen et al. (1994), Mortimore (1998), and Mortimore and Adams in this collection of papers, among others. These writers have found little evidence for the belief that

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erosion is necessarily linked to high levels of population or to poverty, claims which still make frequent appearances in the literature (e.g. Baidu-Forson and Napier, 1998; Higgins et al., 1982; Mainguet, 1998; Ramaswamy and Sanders, 1992). More important, the critics maintain that because the linkages between these variables are unlikely to be simple, they will not be demonstrated without much more solid evidence than yet exists.

Last, we suggest present priorities for research, based on what we call a "local political ecology" approach. Our suggestions are based on a dictum adapted from Lavigne Delville (1997): "*soil degradation* [like soil fertility to him] *can only be understood in its social context*". The Sahelian social context is so variable, as Raynaut (in this collection) emphasises, both in space and time, that policies to manage erosion must have other kinds of information than mere data on its rates, some gross estimates of economic impact, or generalised notions of natural or social causation. We illustrate this argument from our own research in Niger.

2. Research into soil erosion processes in the Sahel

Research into the biophysical processes of soil erosion in the Sahel has asked two sets of question: about soil sustainability and about immediate impact. The distinction is one of scale (Blaikie, 1991; Lambin, 1993). There are situations in which sustainability is of short-term concern, as where erosion is very fast and soil replacement is by comparison slow, but in most cases sustainability is a long-term, national-scale issue. Most farmers are only interested in possible short-term, field-scale impacts. There is an inevitable tension between the two concerns, partly because they are held by different groups.

2.1. Sustainability

The general meaning of "sustainability" has been the matter of substantial debate (Lélé, 1991; Worster, 1993; Murdoch and Clark, 1994; Pretty, 1995). We are mindful of Long's (1992) caution that "sustainable development" is inevitably a source of competing and continuing re-definition and of power struggle, and of "the need to move away from defining sustainability in simple technical terms" (Scoones and Toulmin, 1998). Nonetheless, many believe sustainability to be an important medium- or long-term goal in Sahelian soil conservation (Hailu and Runge-Metzer, 1993; Critchley et al., 1992), and they and this part of our review, need a working definition. In the narrow context of soil erosion "sustainable" can be taken to mean the maintenance of enough soil to ensure crop production, a concept often expressed in terms of the "soil life". Put briefly, soil life is the time over which a soil can suffer erosion before becoming too shallow to support crops (Elwell and Stocking, 1984; Benson et al., 1989). Soil life depends on the balance between inputs and outputs of soil material, and on the initial depth of soil. We look first at the rate of erosion, for it has received the greatest attention.

2.2. Measuring erosion

The physical processes of erosion are very difficult to measure, a point repeatedly emphasised by the scientists involved (e.g. Dregne, 1990; Roose and Sarrailh, 1990; Lal, 1993; Stocking, 1995). Rates vary vastly between soils and slope positions, from meter to meter and from second to second. Most soil erosion takes place in short, intense events, during which there is rapid and complex interaction between the eroding rain and wind, and the resisting soil. Too few or too many of these events may be included in a short period of measurement, introducing uncertainty into the mean values obtained. Without longer periods of measurement these errors are impossible to evaluate, especially in a climate which is as variable as that of the Sahel, and only some of these difficulties are avoided by the use of artificial rainfall to simulate different rainfall intensities, or wind tunnels to simulate different wind speeds (Collinet and Valentin, 1984; Collinet, 1988; Nickling and Gillies, 1993). Measurement is also subject to technical difficulties. Experiments may give very variable results, depending on minor modification of technique (Lal, 1988b; Roose and Sarrailh, 1990). Finally, there are strong spatial-scale effects: rates derived from small plots (the usual form of data collection), are almost always greater than rates collected or estimated for larger areas such as river catchments, because of soil redistribution effects (e.g. Roose, 1977b; Millington 1984; Walling, 1982). These three sources of uncertainty are generally less, though still severe, in water erosion measurement, although there can of course be confusion where wind and water operate together as agents of erosion.

There have been a few bounded plot experiments for water erosion in West Africa. These are plots from which eroded sediment is caught in troughs or storage tanks. Their purpose is to develop an understanding of the factors that influence erosion, so that the results can be extrapolated to other areas. In francophone West Africa, Fournier initiated a network of plots for this purpose in 1954 (Roose, 1977a), and another series was later installed at the IITA station in Nigeria (e.g. Lal, 1985). There have been some plot studies in other locations (e.g. Delwaulle, 1973; Heusch, 1980; Collinet and Valentin, 1984; Collinet, 1988; Mietton, 1988; Millington, 1984), but most have been short term. In the late 1970s, Roose (1977a) listed nine plot studies in francophone West Africa: three in the Ivory Coast, three in what is now Burkina Faso, and one each in Senegal, Niger and Benin. Lal's (1993) survey for the whole of the subcontinent did not list the last of these, but added four in Nigeria and three in Ghana, giving a maximum of 16 for the whole of West Africa. Of these, perhaps five could be said to be in the Sahel and one more could be added from Heusch's work cited above. The longest period of continuous measurement in Roose's review was 14 yr (Roose, 1977a).

As to wind erosion, the only source of information until the last three or four years has been from visibility data (i.e., the extent to which airborne dust carried by wind obscures vision — from which dustiness can be inferred). These are routinely collected at meteorological stations (Middleton, 1985; Littmann, 1991b). There have also been a very limited number of dust collections in traps of various kinds (see Drees et al., 1993). There are no standard systems for the collection of dust, let alone for comparison between these different types of data. The meteorological data undoubtedly show that the frequency of dust storms increased in the 1970s and 1980s, but neither they nor the dust collections allow rates of erosion to be calculated, because the sources of wind-borne particles are difficult to pinpoint. It is possible to "fingerprint" dust sources (Littmann, 1991a; Chapuis et al., 1996), but it is doubtful if field-level estimates of erosion rates will ever be possible from measures of collected dust. More encouragingly, results are now emerging from research which is measuring in situ wind erosion, particularly in southwestern Niger (Chapuis et al., 1996; Rajot et al., 1996; Sterk, 1997; Sterk and Stein, 1997; Chappell, 1998; Bielders et al., 1998) and Mali (Nickling and Gillies, 1993). Some of these are discussed below.

2.3. Modelling erosion

The results from these and other similar studies were intended to allow estimates of erosion rates in the Sahel in general, but only first approximations have yet been attempted. Fournier and D'Hoore (1962) made early continental-scale estimates, based on an aggressivity index of precipitation. More recently, Lal (1993) based his estimates for West Africa on a survey by FAO/UNEP (1979), itself based ultimately on Fournier's estimates, but also using generalised soil maps and erosion rates in similar climates in other parts of the world. Lal complimented these with results from the plot studies. A test of the accuracy of FAO's and Lal's estimates is to compare them with on-site measurements for the part of southwestern Niger in which the authors are working. The FAO/UNEP figure for "potential risk" of soil loss in this area was between 50 and 200 t ha^{-1} yr^{-1}. Lal's figure for "gross rate" of soil loss was 20–25 t ha^{-1} yr^{-1}, although he had earlier quoted a specific figure of 40 t ha^{-1} yr^{-1} (Lal, 1980, see below). Yet Chappell's (1996) measurement of net actual loss over a 30-y period, using the ^{137}Cs technique and a geostatistical analysis, was 35 t ha^{-1} yr^{-1}, on the sandy soils of a relatively well-vegetated area of about 1 km^2.[1] All figures are for wind and water erosion combined. Given the differing definitions, baselines, scales and methods used in these studies, inaccuracies are difficult to assess, but the variance in these estimates seems to be of the order of 50%. Discrepancy of this order is not surprising, given the range of methods.

First approximations like these may be useful discussion points, but they are a poor basis for formulating policy designed to tackle erosion, or the socio-economic hardships it can generate. This is equally true for aggregate generalisations made by several key studies of nutrient depletion and soil nutrient balances in African farming systems (Scoones and Toulmin, 1998, 1999).

More elaborate and detailed systems of extrapolation have been envisaged, but not yet realised. The most common choice of model for extrapolation, in the Sahel as in many other parts of the world, is the universal soil loss equation (USLE) (Wischmeier, 1976). The USLE was explicitly the format chosen when most of the West African plot experiments mentioned above were designed. It has been improved as the revised USLE (RUSLE, Renard, et al., 1991), although many of the fundamental problems remain. An alternative developed for African situations, is the SLEMSA, developed for eastern and southern Africa (Elwell and Stocking, 1982). Stocking and Lu (2000) review some other models. There are very few alternatives for the measurement of wind erosion, the most widely used model being the wind erosion equation (WEQ) (Woodruff and Siddoway, 1965), soon to be replaced by wind erosion prediction system (WEPS). These models were designed to estimate erosion rates from data on rainfall (or wind), slope, soil type, crop cover, etc. There are however, two types of doubt about their use: with the modelling process itself and with its relevance to Sahelian smallholders.

Even in the United States, where they were calibrated with substantial empirical data, some large assumptions had to be made. For all the very real values of erosion plots in the Sahel providing well-controlled, base-line data for the local calibration of models, they are manifestly and grossly unrepresentative of this vast areas in space or in time. Second, the models must be used with great care, as cautioned by their designers and their critics (e.g. Wischmeier, 1976). The USLE and WEQ and their revisions are almost totally empirical; the outcome of a very large number of observed statistical correlations. Many of the key physical processes of erosion are even now not well understood (Rose, 1998). This is

[1] The Caesium-137 (^{137}Cs) technique relies on the fallout from atmospheric bomb testing in the mid-1960s. This produced the artificial isotope Caesium-137, which was distributed over all the earth's surfaces. In brief, if less caesium is measured in a topsoil than is "expected", there has been erosion, and this can be quantified. There are many available descriptions of greater complexities, for example in Chappell (1998), and the papers referenced there.

particularly so for the resistance of the soil surface to erosion (the so-called "K" factor in the USLE), which can often be inferred only as a residual once all the other factors have been controlled; it has proved very difficult to measure directly (Lal, 1988b). Roose and Sarrailh (1990), though generally supportive of the USLE, found "K" to vary widely in experiments on individual soils. "K" is strongly dependent on methods of cultivation and on degrees of surface crusting, which have almost an infinity of variations in the Sahel. Roose (1977a, b) and Lal (1988b) expressed particular concern on this account. It is because of this and similar hesitations about other factors that the USLE is under constant reappraisal. Similar reservations have been expressed in relation to the WEQ (Argabright, 1991) and the WEPS. Second, among the general scientific pitfalls in applying these models, is the sorry state of the environmental and climatic databases upon which modelling would have to depend. These have never been good and are now deteriorating rather than improving in the Sahel region (Chappell and Agnew, 2000).

2.4. Applicability and alternatives

There are however, even more serious problems in applying these models to environments like the Sahel which are so physically and culturally different from the United States for which they were designed (Roose and Sarrailh, 1990). Given its size, the variety of soils and climates, the variability of rainfall and farming strategies in these complex, diverse and risk-prone farming systems, applying existing models could not hope to produce anything but the grossest of estimates of soil flux. We return to this question below in the context of the immediate effects of erosion.

Other approaches to modelling are under development. There have been many estimates of erosion using satellite remote sensing (for land cover data) in combination with other data, as from digital terrain models, climate statistics and soil maps. They range in scale from the global (Drake et al., 1999) to the local (de Jong, 1994). Many, however, depend on models like the RUSLE, whose problems have been discussed above. They are given more credibility when they are calibrated by other techniques, as in the use of geostatistics to estimate the spatial and temporal variability, and measuring techniques like the ^{137}Cs method (see footnote 1), as in the work of Lundén et al. (1990) and Chappell (1998). However, most of these synthetic methods are too expensive to be applied widely and their ability to deal with temporal variability is generally too severely constrained for them to be used in conjunction with social studies, as we advocate below. Nonetheless, the new modelling techniques hold out promise of delivering better estimates of erosion for sample areas.

2.5. Other elements in "soil life"

Data and models on erosion may be limited, but they are profuse when compared to those on the other elements of soil life. The lack of data and the tenuousness of the estimates for these elements in the USA, let alone elsewhere, are remarkable, given their centrality to the concept (Schertz, 1983; Johnson, 1987). In a simple case, soil life depends on the relation between outputs in erosion and inputs from various sources: primarily from weathering (chemical and physical decomposition) of the underlying rock, but also the supply from upslope (in some landscape positions); and dust (again only in some situations). Innovative methods for measuring soil formation by weathering are being tested, and may be able to give accurate estimates in some areas (Alexander, 1988; Pavich, 1989; Lal et al., 1991), but have only been applied to a few sites. In Africa there have been few serious estimates of weathering rates in this kind of situation (Dunne et al., 1979; Stocking, 1984; Mulugeta Tesfaye, 1988; Mulugeta Tesfaye quoting Hurni, 1983; Biot, 1990). Many, but not all, are less than estimated rates of erosion. We can trace only one from West Africa for situations in which erosion and weathering are being balanced: De Graaf and Stroosnijder's data (1994, quoted in Trench and Batterbury, 1999) can be used to estimate a soil life of the order of well over 100 yr in parts of Burkina Faso. Regardless, Lal (1980) hazarded a guess that the soil replacement rate (through weathering) in southern Nigeria was of the about $1\,\mathrm{t\,ha^{-1}\,yr^{-1}}$, a figure that was an order of magnitude less than his estimates of erosion, a combination that produced a very short soil life.

However, many Sahelian soils have very different kinds of controls on soil life. These are the sandy soils developed on stabilised dunes, inherited from the dry periods of the late Pleistocene, which cover a very large proportion of the Sahel, and of other semi-arid areas (Grove and Warren, 1968). These soils, like the loess soils of the Mid-West of the USA and northern China, are not being significantly replaced by either rock breakdown or, at present, by additions in the wind. Nonetheless, many are deep enough to withstand many decades, if not centuries of erosion before the hard rock is reached (thus, even at high rates of erosion they have a long soil life). In many cases, erosion in these sands, if not so fast that soil organic matter and nutrients cannot be recycled, uncovers a soil as good, if not better than the soil that was removed. It was on sandy soils in northern Nigeria, that Olofin, using SLEMSA (1992, quoted by Mortimore, 1998), estimated a "soil life" of many decades. The indifference of many Sahelian farmers to high rates of soil loss on such soils may reflect their recognition that erosion does not seriously damage productivity in the short term (until the soils are very thin, see below). Of course, not all sandy soils are deep. This is a point discussed below.

There is another way in which most Sahelian soils have distinctive soil-life characteristics. They are be being replaced in significant measure by inputs of dust (most of it in the Harmattan winds), which may supply the major agricultural crops, particularly millet, with adequate Ca and K, if not P (Herrmann et al., 1996). On the basis of his ^{137}Cs profiles, Chappell (1996) calculated a dust accumulation rate for the last 30 yr of $3.5 \pm 0.2\,\mathrm{t\,ha^{-1}\,yr^{-1}}$, a figure that compared well with the average of $2\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ derived by dust monitoring over eight years by Drees et al. (1993). Valuable though these inputs are, they are not replacing the bulk of soil lost by erosion. The uncertainties in these data must be remembered, of course.

2.6. Measuring soil sustainability

Our argument about soil sustainability has focused on the on-site effects of erosion, termed "T1 costs" by Pierce et al. (1984). There are also off-site costs, called "T2", which are the costs of the sediment once it has left the fields. These costs are not all negative, as when rich sediment is added to floodplain soils. Nonetheless, T2 costs, as of the siltation of reservoirs or of dust in machinery, are generally many times greater than T1 costs (Piper and Huszar, 1989), and are thus clearly an issue for cultivators and policy-makers. However, if the argument is confined to soil sustainability, unless new paths are explored, physical measurements can only yield results that will be useful to policy after many more years of research, and much more investment in technical expertise, if then. A case study below will show, moreover, that while agronomic research of the sort outlined above can throw light on soil erosion, soil sustainability cannot be judged out of social context.

2.7. Measuring the immediate impacts of soil loss on crop productivity

Here too, the greatest advances have been made in the United States (Fahnestock et al., 1995; Rijsberman and Wolman, 1985; Stocking, 1984). There, and elsewhere, most estimates are based on experiments in which increments of soil are artificially removed. Lal's and others' experiments of this kind in southern Nigeria stand almost alone in West Africa (reported widely e.g. Stocking, 1984; Mbagwu et al., 1984; Lal, 1985; 1988a, b, 1993). The results are alarming. Crop losses were of the order of $0.08–0.26\,\mathrm{t\,ha^{-1}\,mm^{-1}}$ of soil lost (Lal, 1988b). Lal quoted early studies in Burkina Faso, which suggested that an increase in erosion from 1.4 to $13\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ caused a decrease in millet yield from 727 to $352\,\mathrm{kg\,ha^{-1}}$. In the United States, data from desurfacing experiments have been fed into the erosion productivity impact calculator (EPIC) model (e.g. Putman et al., 1988; Benson et al., 1989). However, EPIC and similar models, unlike Lal's work, show that the net costs of erosion are generally small both in the US and globally (Pierce et al., 1984; Putman et al., 1988; Colacicco et al., 1989; Benson et al., 1989; Crosson, 1997), although there is an alternative interpretation (Pimentel et al., 1995). Crosson (1997), using a similar approach, did indeed list the West African Sahel as one of the global "hot spots" for erosion, perhaps following Lal, but his judgement must be regarded as very tentative. The EPIC model has indeed been used for preliminary studies on the effects of erosion on millet cultivation in the Sahel (Michels et al., 1997), but its use was very cautious.

Economists have also used data like these to estimate the costs of erosion at the scale of African states (for example Bishop and Allen, 1989; Bishop, 1992; Norse and Saigal, 1993), with variable results. In Mali, whose environment is quite similar to Niger, Bishop tentatively concluded that soil conservation was worth investment by the state, since it was causing losses of between 0.5 and 3.1% of GDP. Norse and Saigal analysed Stocking's (1986) estimated costs for erosion in Zimbabwe in the early 1980s. They were as high as 16% of GDP, but largely because of the loss of nutrients in the eroded soil.

All these judgements, however, are based on methods that are almost as insecure, if not more insecure than those developed to quantify soil life. Here too, most of the scientists involved in desurfacing experiments, as well as most of the economists, counsel great caution (for example Lal, 1985; Bojö, 1991; Pagiola, 1992; Norse and Saigal, 1993; Stocking, 1988, 1995; Smyth and Young, 1998). There are few studies (far fewer cases than those that measure erosion) in the face of huge variability, for research costs are high. There are also doubts about the effects of rapid removal of soil, which is necessary to achieve experimental results, compared to the effects of slower loss in an eroding field, where topsoil fertility has time to recover from erosion (Stocking, 1984). Another question concerns the balance between the rates at which nutrients are removed by leaching, erosion, fixation or absorption into the crop, for these are likely to be highly dependent on soil type, farming system and the peculiarities of the weather (Roose, 1977a; Norse and Saigal, 1993). It is now widely acknowledged that the thinning of soil only has effects when the soil gets too thin to hold enough moisture for the crop, so that soil loss is not important until the last few decimetres or so (Pagiola, 1992; Xu and Prato, 1995). In addition, there are undoubtedly scale relations between erosion and productivity, which have barely been recognised (Halvorson et al., 1997). Thus, as with notions of soil life, very little is known in a strict agronomic sense about the short-term impacts of erosion on agriculture in the Sahel, and very little more is likely to be known in the near future.

2.8. The evaluation of immediate impact

It is here that Lavigne Delville's dictum has its strongest relevance: immediate impacts can only be evaluated in their social context. We will return to this most fundamental point below, but before that, we must cite three other objections to research, which depend only on controlled experiments. First, by its very nature, scientific research must isolate one or a very few factors from an extremely complex mix of factors of production. If soil loss were to contribute say 10% to loss of yield (which is a generous estimate if we follow Crosson), its effects would be barely detectable in environments where rainfall, pests, crop and fertiliser prices and labour costs and availability have far stronger variable effects. Moreover, all these factors, and more, interact in complex ways. Second, research has yet to incorporate all the factors in the relationship between erosion and productivity. Some of these issues have been discussed above in relation to the USLE. In relation to wind erosion, it is notable that one of its most damaging effects, the sandblasting of young crops, has been found to be too complex to be included in the new WEPS modelling system. Third, it is doubtful if the results of this kind of research could ever be applied to the sorts of agriculture practiced by smallholders. The approach implies that erosion should be controlled by the technical adjustment of abstruse (and not always well understood) qualities like soil erodibility (the elusive "K" factor), the cropping pattern (C), and the conservation practice (P) (both measured by an index related to Mid-Western farming systems) (Roose and Sarrailh, 1990; Roose, 1993; Lal, 1993). This might just be possible in large-scale commercial farming, but smallholders manage their systems much more closely, and, more importantly, they adopt more complex systems of risk management and risk avoidance.

We believe that, given a fresh approach, the outlook for research on the immediate impacts of erosion is much brighter than this review might suggest, but only if it is placed in a smallholder context, as our discussion now shows.

3. Soil erosion and the smallholder

3.1. The smallholder perspective

The debate about soil erosion in the Sahel is slowly but surely being focused on the concerns of those who may be its victims (Mortimore, 1998). The purely experimental, technical approach has had few adherents over the last decade, even among the scientists who had been most deeply involved (Pieri, 1989; Roose, 1993; Stocking, 1986; Lal, 1998). Many forces have driven this major change of opinion. The strongest is the incontestable failure to interest African farmers in soil conservation programmes based on the strictly natural–scientific approach (see de Graaf, 1996; Shaxson, 1985; Scoones et al., 1996). Another source of discontent is distrust of the "crisis narrative" (Roe, 1995), which has been widely employed in discourses about soil erosion (Cour, this volume; Leach and Mearns, 1996), about nutrient balances in indigenous agriculture (discussed in Ramisch, 1999), and about grazing systems (Warren, 1995). Disquiet starts with a simple question: how, if these processes are so damaging, have farmers and herders persisted at all in their rural activities? (Krogh, 1997; Mortimore and Adams, 1999; Scoones and Toulmin, 1998; Warren, 1995). The emerging focus on the smallholder/pastoralist in all these spheres is also part of a general movement to consider local solutions to the development of livelihoods in what Chambers and Toulmin (1991) call "Complex, Diverse and Risk-Prone"(CDR) conditions. This is said to hold promise because smallholders in these environments are inherently experimental, and rapidly adopt new systems when they have evaluated and appreciated their value (Richards, 1991; Batterbury, 1996).

For all this change of heart, the picture of erosion from the smallholder perspective is very incomplete. Chambers and Toulmin conceded that it would not be easy to acquire. Smallholders make use of many different microenvironments, and have very different patterns of cultural and economic behaviour (i.e., they are socially and economically differentiated), even where they live in close proximity. Above all, their risk-avoidance strategies must of necessity be extremely dynamic, varied and flexible (Davies, 1996; Raynaut, 1997).

Until the last few years there have been three main approaches to the study of erosion from the smallholder perspective. One, which can be referred to as "regional political ecology", is traceable to Blaikie's classic *Political economy of soil erosion* (Blaikie, 1985; see Batterbury and Bebbington, 1999; Peet and Watts, 1996). The regional political ecologists rejected the conventional wisdom of the time that erosion (and other forms of environmental degradation) resulted merely from the harshness of the environment, inadequate technologies, or rising population levels. They pointed instead to a suite of processes, operating at different scales and with different periodicities, that conspired to create the conditions under which land degradation occurred. What really mattered, they argued, was the fundamental constraints placed on human agency and creativity by political and economic processes, what Amanor called the "unsympathetic socio-economic milieu" (1994, p. 222). Many aspects of culture and economy were seen to limit the adaptive capacities of human agents, and to force this capacity in certain directions (Davies, 1996).

Another approach was that taken by agricultural economists (summarised in de Graaf, 1996), who recognised the limitations of cost–benefit analysis to grasp the dynamics of why soils are conserved or degraded by farmers. Other tools were developed to account for decision-making in context, notably multi-criteria analysis of long-term investment in soil conservation, and techniques to sensitise survey-derived data to gender and income status (Kunze, 2000; Kunze et al., 1997; Baidu-Forson and Ibro, 1996). In brief, gross margin calculations are used to evaluate the productivity of the land (expressed in monetary value per unit of land), while labour productivity is evaluated as the "return to labour" of conservation, expressed in monetary value per unit of labour (Kunze, 2000).

Third, a wide range of sociological and anthropological studies have aimed to discover why Sahelian farmers behave as they do, by understanding their social "constructions" of erosion and land management, as well as their everyday behaviour, using diverse methods (Adams and Mortimore, this volume; Brouwers, 1993; Gray, 1997; Östberg, 1991; Rinaudo, 1996). The term 'cultural economy' of land degradation has been used in one recent work to describe the mix of market principles and social considerations that guide farmers decision-making over natural resource use (Mazzucato and Niemeijer, 2000, p. 264)

Political ecology and economic analysis, can, however, overlook the "worldviews" and everyday preoccupations of the individual household or smallholder, and ethnographic work is too easily constrained by imperfect knowledge of environmental processes on the part of social scientists. All cases in which erosion occurs are affected by political and economic marginalisation, struggle, land alienation, adaptation and complex decision-making. Moreover, it is rarely possible to examine all of these in equal measure, let alone the full range of "scales" of analysis and processes called for by Blaikie (1985). The general conclusions of the most celebrated recent study in the "regional political ecology" of soil erosion in East Africa, *More people, less erosion* (Tiffen et al., 1994) have been questioned on closer analysis (Murton, 1999). In the economic sphere, evocations of rational decision-making cannot capture local value systems and beliefs. De Graaf (1996, p. 162) experienced difficulty in finding "variables that had any significant effect on Mossi farmers' conservation behaviour" (in Burkina Faso). His framework concerning farmers" decisions about conservation, included only a brief survey of their perceptions (1996, p. 157), while other work has shown that decision-making among the Mossi and neighbouring Gourmantche is highly complex and variable (Ford, 1982; Mazzucato and Niemeijer, 2000; Kunze et al., 1997). The use of standardised survey instruments rarely appeals to farmers (Kunze, forthcoming). The necessary homogenisation of very variable socio-economic circumstances also characterises some recent studies into the relations between biophysical and management processes in eroding landscapes by Stocking and Lu (2000), and Lu and Stocking (2000a, b), though their work does hold great promise for recognising the role of social variability. With some exceptions, most political ecologists, economists, the sociologists and the policy analysts have begun their studies with the assumption that soil erosion is malign,[2] but this assumption begs very large questions, as the discussion above and our case study below both show. It is true that discovering the preoccupations of individual smallholders in these systems is very difficult, but we believe it to be crucial to the understanding of erosion.

3.2. *Local political ecology*

What is needed, we believe, is a sharper focus on local decision-making and a recognition of context, what we term "local political ecology". Our second starting point in arguing for this perspective (our first being Lavigne Delvile's dictum) is Chambers' (1997) observation that natural resources are only part of many elements that make up livelihoods, which exist in very complex environmental, social and political milieux. Land and crop rights are critical to the ability to sustain welfare and these livelihoods (IIED, 1999). Gender, class, ethnicity, political status and other forms of power in turn influence these rights (Ellis, 1999; Scoones, 1998). Access to resources and the ways in which local people evaluate threats to these resources (as of erosion) are functions of the production and accumulation of wealth, and of social status and power over time (Saul, 1988; Berry, 1993; Bolwig, 1996; Rocheleau et al., 1996; Rocheleau and Edmunds, 1997; Schroeder, 1997). We concede that defining a "local" scale of analysis is difficult. The boundaries between the "local" and the "regional" are fuzzy, not least because Sahelian village economies no longer exist in isolation (if they ever fully did), and also because "commodification" has advanced into almost all rural settings (Batterbury and Bebbington, 1999). Nonetheless, it is at the local level — where farming actually takes place — that there is the biggest gap in the research into the part that erosion plays in Sahelian (and in other) agricultural economies.

We place three different connected frameworks as falling more or less under the rubric of "local political ecology". Our own research is of a type that asks about the relations of CDR livelihood systems to their local natural environment. We try to link empirical measures of soil erosion to a (necessarily limited) set of socio-economic variables and human behaviours by individuals and households. Another set of questions is

[2] Batterbury and Kunze were both attached as research students to a soil and water conservation project in Burkina Faso in the 1990s. Our brief was to understand the impacts of land degradation, and the impacts of project land rehabilitation techniques. The need for soil conservation in the region was deemed self-evident, and was rarely questioned.

oriented more to indigenous conceptions of the environment, as in the work of Zimmerer (1994) in Bolivia, Östberg (1991) in East Africa, and Lindskog and Tengberg (1994) in the Sahel. A third type, of more immediate relevance to practical issues of policy formulation, is the so-called "action research" that accompanies development work — where research is multi-authored, participatory, and linked to defined, user-managed outcomes such as new extension programmes or soil and water conservation initiatives that respond better to local needs (Uphoff, 1992; Chambers, 1993). These different sets of question are complementary and not necessarily overlapping. Ideally, all three should be asked about the same agricultural systems before intervention is planned.

4. Case study and its implications

There are good models for developing this kind of "local political ecology" in dryland West Africa. The work of Davies (1996) in Mali, for one, stresses how adaptive strategies in the Inner Delta of the Niger River have been driven by both proximate (e.g. drought) and structural (e.g. long-term land degradation) threats to livelihoods, and mediated though factors such as gender, household size and the existence of co-operative support networks. Mortimore and Adams in northern Nigeria (1999), Adams and Mortimore (in this collection), Raynaut (1980) in southern Niger, and Mazzucato and Neimeijer (2000) in Eastern Burkina Faso all develop detailed "hybrid" methodologies to study the articulation of society–environment relations, stressing flexibility in adapational responses and environmental outcomes. The Danish SEREIN programme (Marcussen and Reenberg, 1999) has looked at various aspects of land use and society in northern Burkina Faso, and studied a small number of communities in order to understand social and environmental change and land use patterns (e.g. Reenberg, 1994; Reenberg et al., 1998; Krogh, 1997; Bolwig, 1996). There are also complementarities in a less detailed study of soil fertility in southwestern Niger by Hopkins et al. (1995).

4.1. The site

Our study, then, links livelihood decisions to soil erosion in the village of Fandou Béri in southwestern Niger (13°31.8039N, 2°33.4486E) (Fig. 1). We have developed a deeper ethnographic understanding of farmer practices than this paper can present, through fieldwork spanning three years and several linked investigations (Batterbury, 2001). In this case, policy impacts were not studied; we wished to see what people did in the absence of substantial external support. Since the collapse of a "seed multiplication scheme" in the village, which had offered seeds and fertiliser to farmers in the 1980 s, very little fertiliser or other external inputs had been applied and there were no development projects or government services operating in the village, despite its relative proximity to the capital, Niamey.

The village is in a wide, shallow valley, filled with now stabilised, Late-Pleistocene dune sands, which thin out northward onto an uncultivable, low ferricrete hill (locally *tondo bon*). Most of the fields, therefore, have sandy, acid soils (locally "*tassi*"), typical of a large proportion in the Sahel (see above) and many other semiarid areas. There are some clayey soils (*botogo*) in the larger hollows between the old dunes, and along the

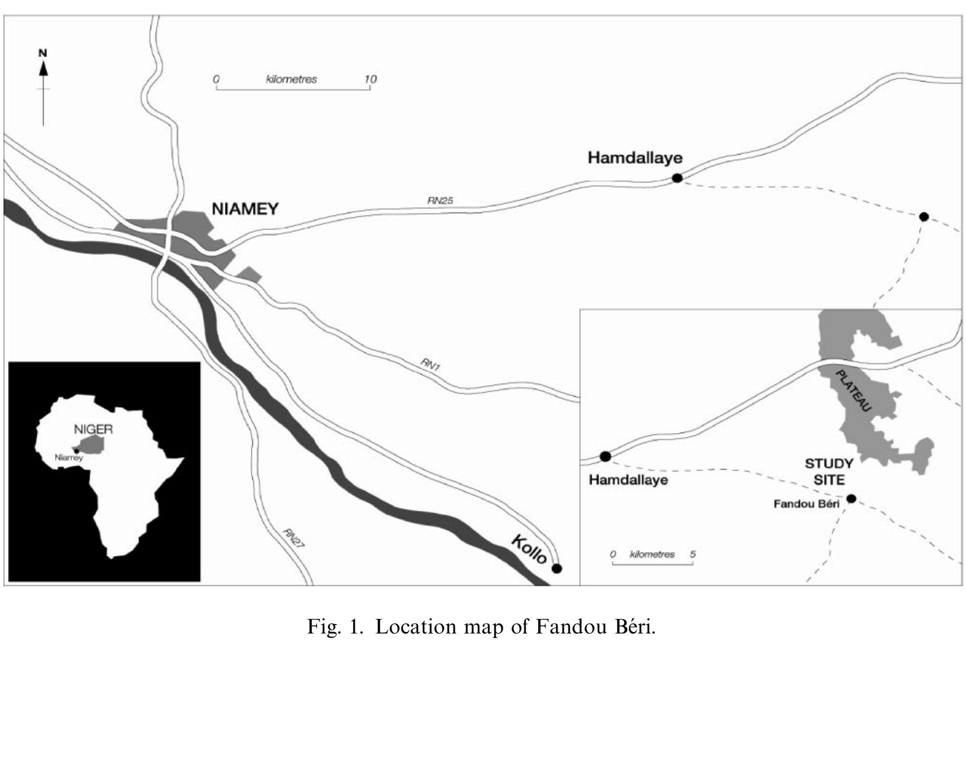

Fig. 1. Location map of Fandou Béri.

narrow course of a now-dry meandering river. The "skirts" of the plateau have fields with harder, silty *gangani* soils that are prone to surface crusting. The farming system emphasises rain-fed cultivation of millet and other crops by the majority Djerma ethnic group, and livestock ownership by the Peul minority, although both groups combine farming with livestock ownership and various non-farm activities. Many households have members who migrate great distances for their livelihood, particularly to trade in goods in rural, northern Ivory Coast. In addition to millet there is a little sorghum, most of it on the clayey soils, and a variety of intercrops such as cowpea, groundnut and hibiscus. There is elementary, but effective control of wind erosion by the laying of millet stalks at the end of the growing season (*paillage*), a procedure that has been found experimentally by Brüntrup et al. (1996) to be very effective. There is a complex fallowing system (Osbahr, 1997), and the turn-round from fallow to field seems to be accelerating in recent years. The reasons are many, and include anticipation of new legislation in Niger that will restrict land ownership to those who can prove either ownership or long-term use — the Rural Code (Lund, 1998).

The *terroir* (territory) is covered by unusually good environmental information, which is important for contextualising new data.[3] Prior to the recent measurements of wind erosion in this area (see above), erosion severity was unsubstantiated. Spaeth (1996) had made some inferences and Lal (1988a, p. 445) quoted rates between 16 and 31 $t\,ha^{-1}\,yr^{-1}$ for this part of Niger, but clearly misreferenced his source of information.

4.2. Research design

We are approaching our research on soil erosion at Fandou Béri from two directions, reflecting our disciplinary backgrounds as social and natural scientists. First, we are measuring the erosion itself. Following earlier work by Chappell (1998) on the northern edge of the terroir, we are measuring erosion over the last 30 yr with the caesium-137 (^{137}Cs) technique (described in footnote 1). From 1996 to 1997 we analysed bulked soil samples, collected using standard sampling methods on 15 fields. These fields, shown in Fig. 2, are farmed by 20 different Djerma and Peul households. Fifteen of these samples have now been analysed.

Fields were selected to be as representative as possible of the range of households, and spanned different soil types. For each of the sampled fields, we attempted to relate the ^{137}Cs-derived measurements and other soil and vegetation data with extensive information on the land managers of those plots. The household's history since 1960, income and expenditure patterns, labour patterns, and demographics of the members of each household have been researched, along with proximate data on farming operations — histories of yields, inputs, pests, tenure, and farming operations on these fields and others farmed. We also have in-depth ethnographic accounts of a few households. Clearly there are many uncertainties with these approaches. The ^{137}Cs technique is a net measure of soil flux over a 30-yr period, and the sampling frame, constrained by cost and logistics, is small in relation to the farmed area. There were also variations in farmers' recall and willingness to participate in repeat visits from local and expatriate researchers over extended periods.

4.3. Some results

Given these constraints, our efforts to develop a rich, local political ecology should be taken as provisional. Erosion rates are broadly in agreement between our study, Chappell"s earlier work on the edge of the *terroir* (1996); and also with short-term measurements of erosion on fields in the vicinity (Bielders et al., 1998). Erosion ranges from 26 to 46 $t\,ha^{-1}\,yr^{-1}$, averaged over a 30 yr period during which the population of the village has swelled, farmers have responded to several serious drought episodes, the Niger economy has swung from uranium-fuelled wealth to serious indebtedness, and post-colonial governance has offered and withdrawn agricultural assistance and a range of local services.

There are associations between the erosion rate and environmental factors such as surface cover, slope and soil type, but in this low, very gently undulating landscape, in which the most extensive soils are the wide expanses of sandy *tassi*, we believe them to be relatively minor. While not minimising these biophysical controls, the study focused on farmed plots, and found significant relationships between erosion rate and social factors. Some of these are illustrated in Table 1, and two examples of bivariate relationships are shown in Figs. 3 and 4. These statistical relationships conceal qualitative variance, and they merely illustrate the sorts of main variables at play in this semi-arid production system: labour, migration, distances, and so-on.

What these data show is that soil erosion at Fandou Béri is a function of many interrelated social and economic variables. The relationship between erosion and distance from the household, shown in the table, is

[3] The village is in the "East-Central" site of HAPEX-Sahel (The Hydrologic–Atmospheric Pilot Experiment, a programme run by NASA (Goutorbe et al., 1997)). Soil maps are available, both from HAPEX (Legger, 1993) and earlier studies (Manu et al., 1991). A nearby village, Banizoumbou, has been intensively monitored as part of the HAPEX and ORSTOM programmes for several years. It is currently being used by the international centres of ICRISAT and ILRI for a wide range of studies including ones on animal manuring (Williams et al., 1995), phosphate budgets (Buerkert and Stern, 1995; Bationo et al., 1995), and wind erosion (Rajot et al., 1996; Bielders et al., 1998) and other work still in progress). Another nearby site was used for a study of micro-variability in indigenous agriculture (Brouwer et al., 1993).

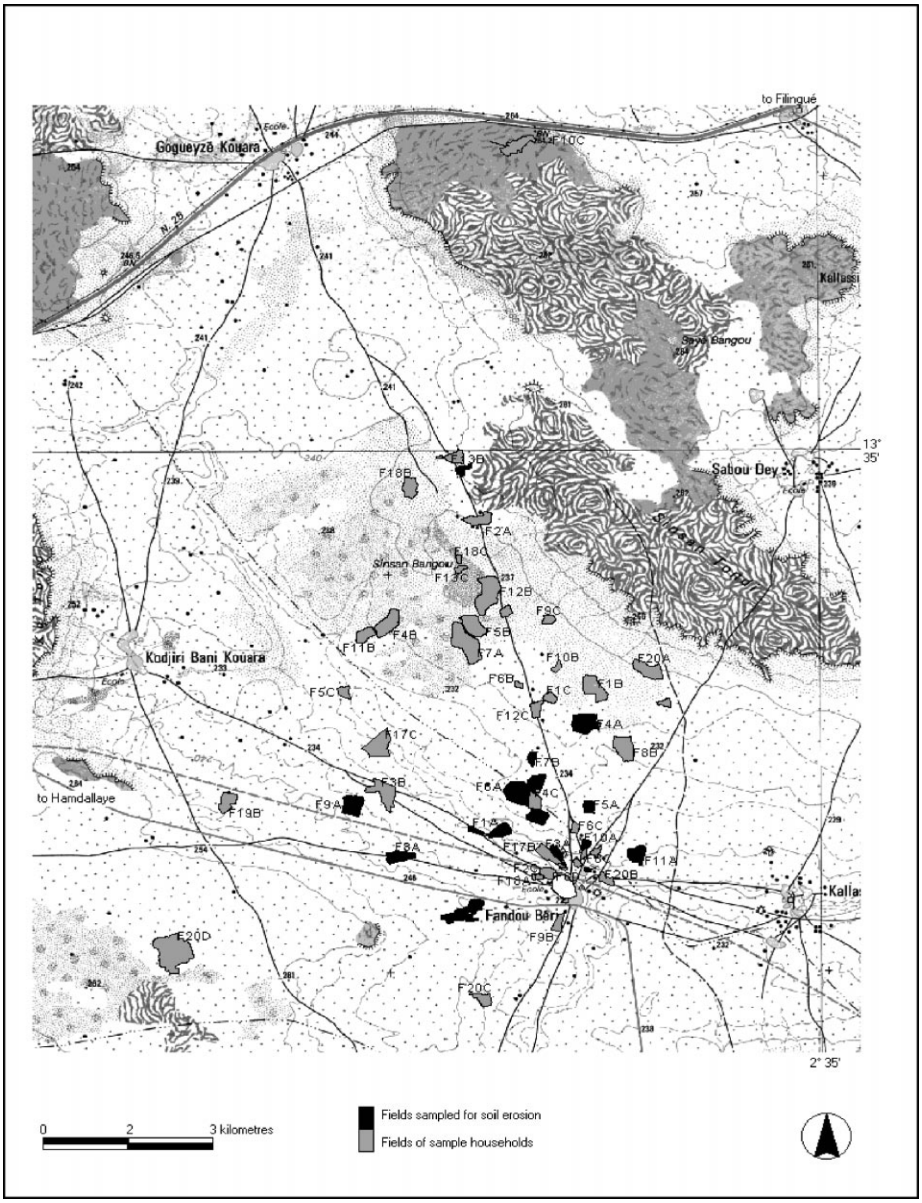

Fig. 2. GIS-derived map showing the location of sampled fields.

Table 1
Variables correlated to soil erosion at the 95% confidence level using multiple regression analysis[a]

Predictor	Coefficient	St Dev	T	P
Constant	40.815	1.986	20.55	0.000
Family labour[b]	− 1.9823	0.5524	− 3.59	0.004
Paid labour[c]	2.1548	0.8463	2.55	0.027
Distance to field (km)[d]	− 4.535	1.237	− 3.67	0.004

Equation: Erosion($\text{t ha}^{-1}\,\text{yr}^{-1}$) = 40.8 − 1.98Paid labour + 2.15Family labour − 4.54Distance to field (km), $S = 2.872$ R^2(adj) = 68.0% for 15 fields

[a]Note: Removed variables include correlations of wealth and tenure (to labour) and soil class and time under fallow (to distance).
[b]Average number of family members working on the field over the 1997 season.
[c]Average number of paid labourers working on the field over the 1997 season.
[d]Distance from the homestead to the field in kilometres.

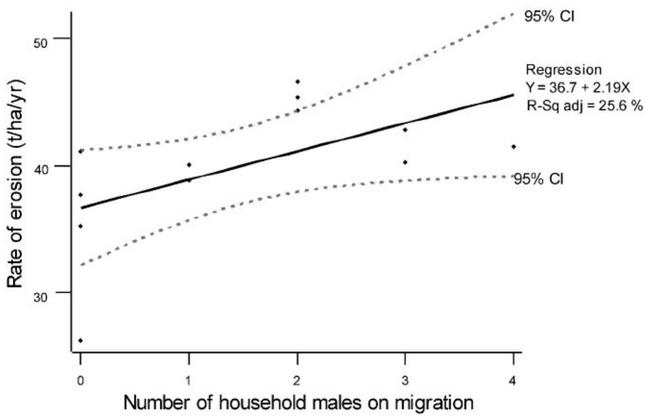

Fig. 3. Bivariate regression plot of the relationship between the rate of erosion and level of male household migration.

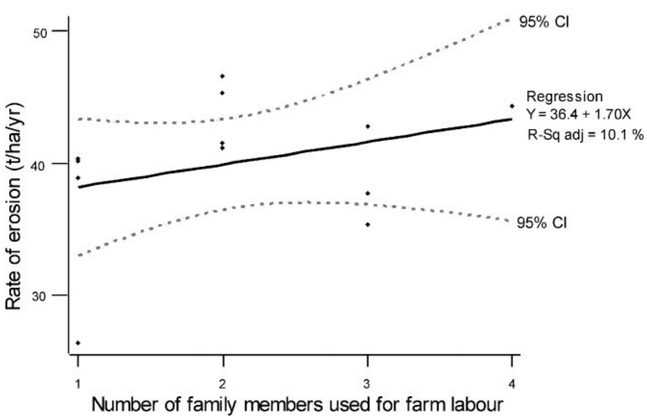

Fig. 4. Bivariate regression plot of the relationship between the rate of erosion and size of household family labour endowment.

actually non-linear, and reveals the first way in which the availability of labour is critical. The low labour investment required to maintain nutrient inputs explains the occurrence of the lowest rates of erosion in the "in-fields" very close to the compounds (this is not shown in the data — see Osbahr, forthcoming). A higher level of investment in soil protection and manuring close to settlements is common in other parts of the Sahel (Prudencio, 1993). But a lower labour input is also revealed in the zone of sandy *tassi* soils just beyond these in-fields, which have higher rates of erosion. As farmers have expressed it, these fields are repeatedly cultivated because of their relative accessibility, their landholding status, and the perceived benefit in growing cereal crops on *tassi* soils in dry years. Pressures from the nascent Rural Code, and uncertain millet yields, are pushing farmers towards continuous cultivation or shorter bush fallowing on these fields. Inflation and loss of subsidies has pushed up the cost of inputs such as inorganic fertilisers, and farmers rarely use them. These sandy soils are also the soil type that are most prone to erosion in the *terroir*.

The relationships between erosion and social factors are more complex than these generalisations about distance, soil type and labour input suggest. Labour input is key, as other studies have shown (Mortimore and Adams, 1999). Male migration, expressed as a percentage of available household labour in a given year, is important. The rate of seasonal labour movement out of this region to the northern Ivory Coast, and other destinations offering a chance of temporary employment for men, is high. But households each have a diverse portfolio of income generation activities, and it is possible to glimpse the effects of income diversification on the landscape, by walking through the fields and talking through labour allocation decisions with households in which labour is short during the growing season. In one Djerma household, the male farmer concentrates on agriculture, but his wife has a diverse selection of activities including fuelwood cutting and sales and raising small stock and cattle for the market. Their offspring assist with all of these activities, as well as engaging in seasonal migration. Such households may work together to clear and plant their dispersed plots, but may then choose not to invest further in some of them if the rainfall is low, or if they do not have access to adequate labour or manure in the appropriate season. The abandoned fields (or parts of these fields) may erode in the early part of the season when wind speeds are highest and the crop has yet to provide adequate protection. All or some of the crop may be lost, but the household is able to withstand the loss because it is engaged in a range of off-farm activities that yield cash enough to purchase grain. At the root of this pattern is a workable, locally appropriate strategy of risk management. Thus investment is not exclusively in very risky agriculture, but also in less risky enterprises, such as livestock rearing, the informal sector, or seasonal migration — a pattern of *productive bricolage* that is common to many poor farmers (Charmes, 1999; Bryceson, 2000). We noted that in Fandou Béri migration is generally a feature of richer households or those with more members, partly due to the high costs of transport to migrant destination zones. Migration, as Cour argues (this issue) helps farmers cope with poor harvests and gives them greater choice and flexibility.

The pattern at Fandou Béri is very comparable to the one discovered by Mortimore and Adams (1999) in the village of Dagaceri in northeastern Nigeria. We have gone beyond that study in offering insight into the environmental outcomes of social patterns. In general terms, it appears that erosion is the consequence of decisions either to invest or dis-invest in the management in particular fields at particular times. Alternative incomes allow the sacrifice of agricultural investment when the system is stressed, and this can lead, incidentally, to erosion. These decisions are themselves the outcome of choices that are nested within the broader political economy; for example, Niger's balance of payments crisis has reduced the opportunities for schooling and urban employment that would take more people from the area, and livestock prices fluctuate according to the buoyancy of the sub-regional market. The social relationships whose outcome may be erosion are therefore in a state of constant readjustment, at many scales, as they respond to prevailing economic and environmental conditions. The drivers of change have complex outcomes across the agrarian landscape, and alterations in biophysical conditions (for example erosion) themselves influence decisions and strategies.

5. Implications

The ways in which erosion becomes "socialised" and incoporated within Djerma and Peul risk management decisions are important for broader understanding of the problem. First there is an implication for sustainability in rural environments. The relationships between erosion and social factors at Fandou Béri suggest that farmers are opting for economic sustainability (livelihood and household reproduction) before environmental sustainability (soil and water conservation, extending soil "life"). Put more starkly, it could be said that that short-term survival may require soil erosion to run its course.

In the longer term, however, if soil continues to be lost at the measured rates, the fields on marginal land in the *terroir* will have very short remaining lives. In other words, they may be in imminent danger of becoming unworkably thin, as erosion reaches through *tassi* to *tondo bon*. If they noticed these losses, it is doubtful if most farmers would be concerned, because these fields are already poor and many are also distant, and because there is still, evidently, a supply of better land, as Fig. 2 shows. But this process is a clear potential threat to longer-term environmental sustainability, and brings our argument back to the question of research priorities. How could the limited funding available for research be focused on processes like these? We believe that, if the question is restricted to research on soil life, it is easy to answer, at least for Fandou Béri. A small investment in some of the newer methods we have described could actually answer questions about longer-term sustainability. For example, Olofin's model (1992), and a survey of the depth of the sandy soils would provide models for the long-term prognosis for the loss of fields, under different assumptions about erosion rates.

The interpretation of the results, however, would depend on the value placed on the soil in local and national contexts, and its role in the provision of livelihood security. This in turn depends on what happens to the farming economy of this part of the Sahel. The pattern of clearing some large fields, and giving them little investment is likely to remain a major part of the general risk-avoidance portfolio, under the existing constraints on labour and capital. If these constraints were overcome and smallholders chose to move more of their capital into livestock, as many Djerma in this region wish to do (Batterbury, 2001), then they might require less land for farming. Alternative sources of income would be opened up, and there might be direct access to more manure. If more Djerma adopted a pattern of intensive farming with direct manure inputs to smaller fields, as the Peul agro-pastoralists have done, then the loss of a few marginal fields might not be serious, even to the long-term future of agriculture in the village.

If, however, soil were to be lost at a high rate across Niger's agricultural zone, it might jeopardise national millet production. If the state took this threat seriously, it might wish to encourage a programme of soil investment, for example mirroring that of post-colonial Burkina Faso where millions of dollars were invested in large-scale rehabilitation exercises. This would only be successful if it acknowledged the logic of livelihoods. At Fandou Béri a keystone of this logic is flexibility as part of a total investment strategy, as interviewees revealed to us. The maintenance of soil is quite often a low priority. Inputs of phosphorus (Buerkert and Stern, 1995), the availability of labour for weeding and transporting manure, sporadic attacks by pests, and the amount and timing of rainfall are much more prominent concerns. A development programme that did not accommodate this logic would either be ignored or, if not, disrupt a well-developed risk management strategy that allows for these other constraints.

In truth, our analysis is likely to find that erosion has a much more complicated ætiology at Fandou Béri, as it must in all Sahelian farming systems. Our kind of local political ecology exposes the uniqueness of the adaptive responses of households and individuals, while showing the regularities in the social and economic constraints under which these individuals operate. The household-to-household differences we have found at Fandou Béri would undoubtedly be magnified, were we to compare different villages in different ecological, social and economic conditions (say along some of the economic gradients in the WALPTS model (Cour, this collection). In some villages soil sustainability would be a live concern, the object of frequent debate and discussion (as it already is in some parts of Burkina Faso —Batterbury, 1996). In others, a very distant one. In some, erosion control would yield immediate returns; in others, it would be a minor consideration (de Graaf, 1996). In some, capital and labour would be available for conservation activities; in others there would be little for either. The state might regard sustainability in some villages to be more critical than in others. A clearer picture is unlikely to emerge before both social and natural scientists, working together, have studied more ecological and social conditions in many more locations. At present, a small number of windows opened up by monitoring and research are providing partial views of an extremely diverse landscape.

6. Conclusions

For all its long and creditable history in the Sahel, soil erosion research still has a long way to go before it can produce answers that are relevant either to long-term planners, or more crucially, to the majority of Sahelian farmers.

Questions about soil sustainability have not yet been fully answered, even as they may be getting more urgent. Our review has shown that answers will not come quickly, unless, possibly, new techniques are integrated with the conventional, established ones to produce more comprehensive and accurate models. Our case study showed that one way to move towards conclusions about sustainability in some situations might be to conduct a selection of quite simple scientific analyses of soil sustainability at the village scale. Nevertheless, in the Sahel as a whole, as at Fandou Béri, our dictum holds for soil sustainability as strongly as it holds for the immediate impact of soil erosion: the results of any analysis can only be understood in social context. The social, or anthropological context of sustainability is all the more complex because it involves imponderables about the future and because it transgresses scales in time, space and in terms of political control over land and decision-making.

We believe that research into the immediate impact of erosion on yield also needs thorough rethinking. Our review and case study have shown, we believe, that social contextualisation is even more critical to this question. Thus appropriate, contextualised research (in addition to contextualised intervention), is vital to every part of the project, a conclusion that we share with Scoones and Toulmin (1999). The primary unanswered questions are: does soil erosion threaten the short- or long-term welfare of farmers? What is its biophysical and social ætiology in the real world of agricultural communities? And, how, if it is a problem, might it be better accommodated as part of livelihood strategies? These questions can only be answered by research in which the social context, “soil life” and soil productivity in relation to erosion are all studied together in the same place. This kind of research needs much refinement. Its development lags behind the established work being carried out by experimental agronomists, economists and other scholars, yet it is closer to the locus of the problem.

Acknowledgements

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