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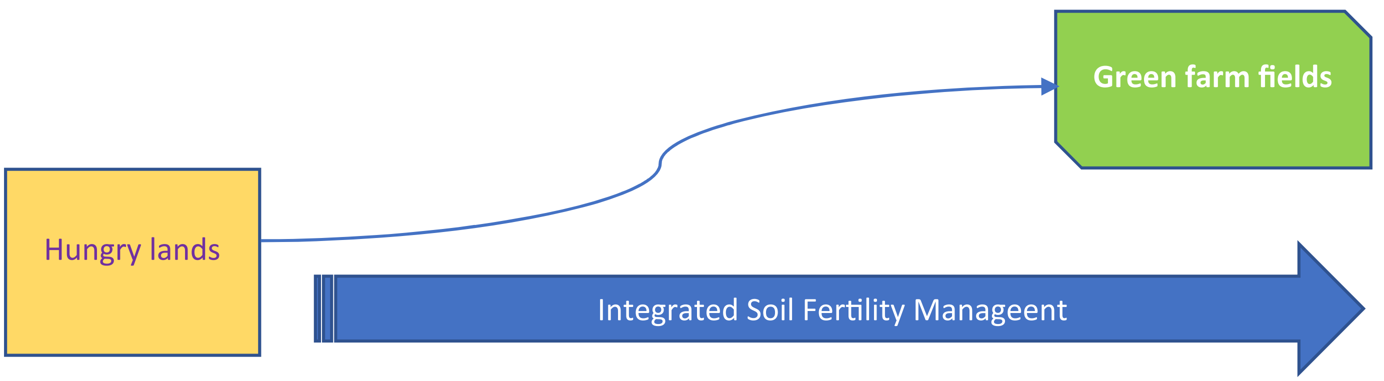

ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

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Abstract: In Benin and many other cotton-producing countries of West Africa, unsustainable natural resource management is hindering agricultural growth, food security, and poverty reduction. This study addressed the sustainability of fertilizer-based soil fertility management practices in Benin. It diagnosed the relationship between differential soil degradation status over space and fertilizer use in cotton production systems. Referring to sound land use principles, it found that present fertilizer use practices overlook the spatial differences in soil fertility status in export-oriented cotton production systems. Considering more relevant short-run fertilizer needs based on desirable fertilizer doses, the potentials for sustainable fertilizer use were then assessed considering the likelihood of change towards best practices of integrated soil fertility management. More rational fertilizer use practices will be critical in the future to inducing higher cotton yields while preserving the environment. Adjusting current fertilizer recommendations to site-specific soil conditions is urgently required to enhance the sustainability of cotton production systems in Benin. Fertilizer policies will need to rely on updated information on soil and land

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PUBLIC INTEREST STATEMENT

Extensive cotton production and inadequate fertilizer use is leading to land degradation, food insecurity and growing poverty in cotton growing areas of West Africa. Soil fertility maps are quite obsolete because of the lack of high-level modern expertise in the field and related high cost. This study used a socio-environmental approach to diagnose the relationship between soil degradation and fertilizer use in cotton-growing areas of Benin, and provided evidence of an inadequate link. Considering desirable fertilizer doses based on best practices of integrated soil fertility management, short-run fertilizer needs were assessed and poor potentials for sustainable intensification were revealed. Fertilizer policies should urge to monitoring soil dynamics, updating fertilizer recommendations to site-specific soil conditions, and innovation in fertilizer use knowledge management. This is key to enhancing the sustainability of cotton production systems and improving agricultural productivity and net incomes among cotton growers.

use dynamics, and be innovative enough to induce a steady increase in agricultural productivity and improved net incomes cotton growers.

Subjects: Environment & Agriculture; Environmental Studies & Management; Development Studies, Environment, Social Work, Urban Studies; Economics, Finance, Business & Industry

Keywords: environmental degradation; soil fertility; agricultural intensification; cotton production sustainability; potential

1. Introduction

Poor soil fertility management is a subtle form of natural resource misuse which is overlooked whereas it hinders economic development through decreasing agricultural productivity and growing food insecurity (Ndufa, Cadisch, Poulton, Noordin, & Vanlauwe, 2005). Indeed, the diversity and peculiarity of different ecological features associated with the African continent demand that a holistic and all-inclusive approach of soil fertility management be devised instead of a one-size-fits all strategy commonly pursued by national governments and international development partners (Oluwatoyin, Kolawole, Mogobe, & Magole, 2013). The widespread soil nutrient mining in Africa[1] has led to expansion of the agricultural frontier and the opening up of less favorable soils for cultivation. This is a scenario for disaster over the long run, given the difficulty of restoring tropical soils to productive capacity (Morris, Kelly, Kopicki, & Byerlee, 2007). In West Africa, cotton production for export with inadequate soil nutrient management is a typical example (UEMOA, 2013). This includes extensive land use with low fertilizer application or backward intensification where fertilizers are applied with little consideration for the differential soil fertility status of cultivated lands (Smaling, 1993; van Duivenbooden, 1995). Bellwood-Howard (2014) observed that market-oriented green revolution approach with emphasis on inorganic fertilizer and credit among African farmers does not allow room for them to practice site-specific soil fertility management (SFM) and subsistence mechanisms that they have developed as responses to risk. Among other reasons, high levels of indebtedness accounted for most.

Fertilizer use practices in cotton production systems of francophone West Africa are inappropriate and are leading to soil nutrient depletion and rapid land degradation (Saidou, Kossou, Acakpo, Richards, & Kuyper, 2012; UEMOA, 2013) and to the inefficiency and low profitability of fertilizer use. Yet, the terms of trade of cotton-producing countries have been declining since the mid 1990s. Recent trends are quite alarming as average increases in fertilizer prices are about three times the increases in crop price (Ivo, 2008). In Benin, in spite of the injection of government subsidy funds up to 67.1 billion CFA francs in the cotton sub-sector since 2000/2001, farmers' income has been declining since 2003 in relation with growing input prices and low producer prices (MEF, 2010). As a result, food insecurity and poverty have expanded (UNDP-Benin, 2011), leading to environmental degradation, even more rapidly in the cotton-producing zones (Houngbo, 2013). Yet, these zones are usually praised to be better off than others.

This paper is about agricultural sustainability in the Republic of Benin, with reference to soil degradation and fertilizer use in cotton zones.

In Benin, agriculture accounts for 39% in the GDP, employs 70% of the active population and contributes 90% of total export earnings (Benin, 2008). However, its annual growth of 2.7% over the 1990–2004 period (Benin, 2010) and around 3% in 2011 has not yet substantially overtaken population growth which reached 3.25% p.a. in 2013 (DDC, 2013). Actually, low-yield cotton production is the main contributor to agricultural growth while food crops' production is lagging far behind and cannot meet the growing urban food demand. The country turned to cotton as its major export crop after its palm oil's competitiveness in the world market drastically decreased in the late 1980s. A state marketing board (SONAPRA) was then created in 1983 to manage input supply to farmers and cotton ginning and exportation to the world market. In the 1990s, the country implemented structural adjustment programs and economic reforms, including trade liberalization, in response to domestic and international pressures for good governance and macroeconomic stability. As a matter of fact, agricultural sector reforms mainly targeted the cotton sub-sector, which provides about 37% of the country's export revenues and 70% of agricultural exports (AProCA, 2008; Kpadé, 2011). However, low productivity and non-sustainability of agriculture in cotton zones still constitute real concerns for the country's economic development.

The main fertilizers used in Benin include the cotton complex (14-23-14-5S-1B), the cereal complex (15-15-15) and urea (46% N). Following market liberalization in 1992, fertilizer consumption first dropped, then increased rapidly thereafter to reach 114,000 metric tons (MT) in 1999, compared with an average of no more than 20,000 MT between 1966 and 1991 (IFDC, 2005). However, this growth was due to an accelerated extension of cultivated areas in response to attractive cotton world market prices in the early 1990s. Cotton areas increased sharply from 26 800 ha in 1982 to 378 000 ha in 1998 (Kpadé, 2008), and then decreased slightly to 347,000 ha in 2013–2014 (UEMOA, 2014), but this area expansion did not translate into similar increase in fertilizer use intensity (amount/total ha cultivated), and cotton yields remain low. Since 1998 the average yield ranged between 1 and 1.1 ton/hectare (Togbé, 2013) against a potential estimated at around 3 tons/ha.[2] Soil fertility management practices remain unsustainable. Between 2000 and 2005, farmers sharply reduced cotton areas (and fertilizer use) up to 50%, in reaction to declining world cotton prices and a disorganized domestic market. When national and international stakeholders, including the World Bank, urged for a healthier management of the cotton industry farmers rather resumed with area expansion, although the PARFC and PARFCB projects enabled yield increases in a few districts.[3] Cotton production increased to 451,000 MT in 2016/17 and is expected to reach more than 500,000 MT in 2017/18, owing to a new support from the newly elected President/Government to boost cotton production.[4] However, the increased cotton production observed is due more to land expansion than productivity increase. Indeed, although total fertilizer consumption increased (not beyond 100,000 MT/year), land expansion resumed more rapidly leading to only a little increase in fertilizer use intensity.

Overall low cotton yields indicate that current fertilizer recommendations in Benin are inappropriate. They ignore nutrient use efficiency, which is the essence of sustainable fertilizer use (Igué, Gaiser, & Stahr, 2004). They are obsolete, as they overlook market trends of other crops. Although maize has become a commercial crop while remaining a staple food crop (FAO-Bénin, 2015), it often gets only leftovers or residual effects of cotton fertilizers in cotton-cereal rotations (Saidou et al., 2012). As a result, there is an inadequacy between spatial differences in soil fertility status and fertilizer doses applied, and this leads to low efficiency, low profitability and reduction in demand, especially when cotton/fertilizer price ratios sink. The said recommendations are perpetuated by fertilizer supply policies that are anchored on a rigid licensing system held by institutions working under a hidden agenda set by monopolies (Honfoga, 2013). In such conditions, fertilizer use intensity in the complex cotton cropping systems, including food crops at various degrees, will remain low and sustainable agricultural intensification cannot happen. Sinzogan (2006) observed that current pest management recommendations in Benin do not fit well with the range of socioeconomic problems farmers are facing, and that socioeconomic interventions need to complement technical R&D advices. This is also true for existing fertilizer recommendations.

This study aimed to show that current fertilizer use practices in cotton-based cropping systems in Benin are not congruent with the differential land degradation status across the country. The inadequacy of pan-territorial fertilizer recommendations is demonstrated and more environmentally sound practices are suggested. The paper advocates for rational use of fertilizers and related soil fertility-enhancing technologies to promote a sustainable agricultural intensification in Benin.

2. Literature review

This section highlights the theoretical background of the study. A few previous conceptual works on soil degradation vs. soil fertility, fertilizer demand and potential for sustainable fertilizer use are summarized.

2.1. Soil degradation as a proxy of soil fertility depletion

Soil degradation, which is the most important aspect of land degradation in West Africa, refers to a loss of soil productivity. However, the concept of land degradation is valued-laden as it embraces many perceptions that make soil degradation actually very difficult to measure. Indeed, a change in productivity cannot be attributed solely to a change in the quality of the soil. Productivity is at least as much affected by changes in water availability, agricultural, or range management practices, or in the case of cultivated land, factors such as labor input, technology, and crop selection. As a consequence, biomass production (or crop yield) can only serve as a first proxy to soil degradation. It needs to be supplemented by corroborative evidence from actual measurements of the state of the soil (Mazzucato & Niemeijer, 2000, pp. 115–116). These authors have extensively discussed how problematic is the operationalization of the concept of soil degradation. Nonetheless, soils' physical and chemical properties are often correlated with crop yields in the case of cultivated lands, and science-based measurement criteria (lab-measured soil properties) may also agree well with farmers' perceptions. Field extension agents refer to such perceptions and their own observations when asked to assess the soil fertility status of those lands. From farmers' experience, the occurrence of certain weeds on a field (whether cultivated or not) indicate a substantial decrease in soil fertility (Dangbégnon, Nederlof, Tamelokpo, & Mando, 2010). This may be correlated with some basic soil nutrient deficiencies. For example, Saidou, Kuyper, Kossou, Tossou, and Richards (2004) assessed soil fertility status on the basis of dicotyledonous weeds, soil texture and color, and soil fauna (earthworm casting activity). They observed that farmers of the Atacora region of Benin have adapted their cropping systems to the local environment by developing traditional and new strategies and activities that could contribute to maintain or enhance crop productivity. In the present study, the observed soil degradation is assessed based on visual appraisal, as a proxy of soil fertility depletion or proxy opposite of soil fertility. This method has some previous references. ISRIC (1991, 1992) used the "low: 1, average: 2, high: 3" values as weights to factor land areas at those soil degradation levels and assess the relative severity of the phenomenon in Benin and other West African countries.[5] In Togo, Brabant, Darracq, Egué, and Simonneaux (1996) and Abbey and Adou-Rahim-Alimi (2003) also used a similar approach to assess soil degradation (1–2: lowly degraded; 3–4: moderately degraded; 5–6: highly degraded). In Benin, the cotton branch of the national agricultural research institute evaluated soil fertility status by relying on farmers' perceptions on a similar scale (0: poor soils; 1: moderately fertile soils; 2: fertile soils; 3: very fertile soils) (IFDC, 2005, p. 7). In all above cases, the method has the advantage of enabling a rapid appraisal of the soil fertility status of large regions at low cost, compared with the laboratory method. The latter requires expensive soil sampling and analyses while not always leading to a unanimous appraisal of soil fertility (Mazzucato & Niemeijer, 2000). In our study, the visual method was based on ad hoc soil fertility variables (original nature of soils, general state of the landscape, change in vegetation, trends in crop yields) that extension agents and farmers appraised as a whole to estimate average soil degradation levels.

2.2. Determinants of fertilizer demand

The process of fertilizer demand is complex. Many agronomic and socioeconomic factors influence farmers' decisions about fertilizer use (types, methods of application, doses, target crops, etc.) (Tshibaka, Honfoga, Têvi, Houngbo, & Dokoué, 1992). Initial soil fertility status is the most important agronomic factor to start with (Mokwunye, de Jager, & Smaling, 1996). Other major determinants of fertilizer use and sustainable farming systems include weather (in general), water availability/rainfall, cropping systems/crop patterns and their market orientation, livestock endowment, and off-farm income (Ebanyat et al., 2010). Soil fertility/degradation status is a combined effect of these factors and determines the amount of fertilizers to be used now or in the future to compensate soil nutrient extraction by crops and soil nutrient losses through water and wind erosion, leaching, etc. Based on such appraisal, farmers should adopt soil and water conservation techniques that reduce nutrient losses. The fertilizer demand process emphasizes the relationships between fertilizer use intensity and some critical determinants of fertilizer adoption (soil degradation status, farmers' technical skills and cropping systems, land and labor availability, farm household income, credit accessibility, diffusion rates of soil fertility-enhancing technologies, and risks and uncertainties associated with input/output markets). These variables interact with each other at various degrees to determine the agronomic efficiency and profitability of fertilizer use, and at last fertilizer demand (Baum & Heady, 1957; Dudal, 2002; Minot, Kherallah & Berry, 2000). Therefore, focusing on sustainable land use in agriculture, the realistic estimates of country's fertilizer needs should be calculated based on the principles of integrated or sustainable soil fertility management (ISFM) in existing cropping systems, building on soil fertility status before fertilizer application and crop production constraints and objectives.

2.3. Principles of fertilizer use sustainability

The sustainability of agricultural intensification is highly dependent on that of fertilizer use. Poorly designed investments in agricultural intensification are particularly risky in Africa whose environments are fragile (Breman, 2000, p. 17). Therefore, reasonably desirable fertilizer doses should be applied, and fertilizer demand forecasts should be made accordingly. Such doses in cotton-producing zones should incorporate differential soil degradation status, as well as the potential yields that reflect farmers' intensification options[6] and obey to the principles of integrated soil fertility management – ISFM (Breman, 1999). The thrust of the ISFM paradigm is that organic treatments are valuable primarily as a means toward increasing the agronomic efficiency of the "entry point," inorganic fertilizer (Vanlauwe et al., 2010). Recommended fertilizer doses should take into account soil conditions, so that relatively small amounts are applied per ha when soil is not degraded, and vice-versa. Only then would such above-mentioned doses make sense and prompt farmers to adopt them. After several decades of extension services for modern agricultural inputs' adoption in sub-Saharan Africa, diffusion rates and crop yields are still low. The approach proposed here is likely to bring about long-lasting positive changes in fertilizer use practices. For example, ICRISAT's scientists developed an innovation called micro-dosing which consist in placement next to plant roots of the amount of fertilizer which is just needed (ICRISAT 2009, 2012). This technique ensures that even small, yet affordable, doses of fertilizer applied at the right place at the right time vastly benefit the crop (William op. cit.). Therefore, fertilizer use advices should rather rely on micro-doses to enable the majority of farmers to adopt that technology and increase their incomes. This has been recalled in the FAO campaign "Produce much with less" over the last 10 years.

According to ISFM principles, sustainable fertilizer use should take into account both market opportunities (Dudal, 2002, p. 18) and the level of natural resource exploitation. Breman (1999) highlighted that when designing a soil fertility improvement strategy, the situations of under-exploitation, intensification, and over-exploitation should be distinguished, while manure/soil amendments and counter-erosion techniques are recommended in all situations (Table 1). ISFM is aimed at increasing land productivity using cost-effective soil fertility-enhancing technologies, including fertilizers, organic matter, and soil conservation methods (Breman, 1997; Breman & Debrah, 1999; Dudal, 2002; Tshibaka et al., 1992). The pan-territorial recommended dose in Benin assumes that soils are exhausted or degraded everywhere in the country, which is not true. Applying low to moderate doses to maintain the fertility of lowly degraded/fertile soils is justified in the situation of under-exploitation, where ecological or biological/low input agriculture is advised (Breman, 1999, p. 13; Breman, 2000, p. 9).

The ISFM principles are useful for understanding and assessing a region's potential for sustainable fertilizer use and agricultural intensification.

2.4. Potential of sustainable fertilizer use and agricultural intensification

The capacity a region has to achieve maximum crop yields and to keep them over a long period expresses its potential for a sustainable agricultural intensification. It is the capacity to achieve long-run optimum productivity, depending on the time horizon specified, while keeping or improving the quality of natural resources (Dixon, Gulliver, & Gibbon, 2001, p. 12 et p. 35; Schreurs, Maatman, & Dangbégnon, 2002, pp. 67–69). In Benin, Weller (1999) addressed the potential of agricultural intensification as follows: "To what extent agricultural intensification practices will contribute to food supply or what are the agronomic potentials of Benin?" Actually, not only agronomic factors are important. The potential for intensifying the production of a range of crops within complex cropping

Table 1. Principles and technologies for integrated soil fertility management (ISFM) and implications for the dose of fertilizer use

Situations	Probable soil degradation status*	Principles	Technologies	Desirable dose* of mineral fertilizers
General		Prevent soil nutrient losses	Fight against water and wind erosion, and bush fires	
		Prevent the loss in soil structure	Organic matter management	
Under-exploitation	1 (lowly or non-degraded soils)	Compensate nutrient exportations using “green fertilizers”	Fallows, leguminous plants/crops and agro-forestry	Low (1/3 of optimal dose corresponding to potential yields)
Intensification	2 (moderately degraded soils)	Increase water and nutrient availability	Integrated water and nutrient management	More than moderate (2/3 of optimal dose or more)
Over-exploitation	3 (highly degraded soils)	Recapitalize and improve soil fertility	Integrated use of amendments and mineral fertilizers	High (3/3 of optimal dose)

Source: Adapted from Breman (1999).

*These columns are added by us to Breman’s original table. In the field, the situation of intensification becomes quickly that of overexploitation because of high population density. The method for adjusting the recommended dose assumes the following relationship: Desirable dose = (Dose of potential yield) × (relative degree of soil degradation).

systems is associated with the quality of resources (soils/agro-ecological conditions, infrastructure, access to credit and inputs and farm equipment, skills of extension/research services and farmers), and the long-run strategies for using them (Breman & Debrah, 2003; Schreurs et al., 2002, p. 68). These factors reflect the natural potentials and the existing technical and economic opportunities for intensifying agriculture (IFDC, 2006). Then, how to measure the potential for agricultural intensification? From an agronomic perspective alone, Weller (1999) used a complex formula that incorporates soil, climate/weather and crop data to evaluate the agro-ecological potential of maize production in southern Benin. In this paper, the unit of observation is not a crop but rather the soil carrying various cropping systems in different agro-ecological zones, and we focus on a fertilizer-based sustainable agricultural intensification.

3. Materials and methods

3.1. The study approach

In designing fertilizer policies, reliable data on soil fertility status, applicable fertilizer doses, adoption rates and country’s fertilizer demand in the short and long run are required. The study wanted to illustrate a socioeconomic approach for revising pan-territorial fertilizer recommendations based on a participatory assessment of differential soil degradation status by district for a wiser policy for fertilizer procurement and use in Benin. That approach is inspired by the Framework for Evaluating Sustainable Land Management (FESLM) which is defined as “a pathway to guide analysis of land use sustainability, and connect all aspects with the multitude of interacting conditions (environmental, economic and social)” (Smyth, Dumanski, Spendjian, Swift, & Thornton, 1993; van Duivenbooden, 1995). Considering the need for cost-effective fertilizer policies, it draws specifically on the principles of sustainable or ISFM and includes the estimation of: (i) adjusted fertilizer doses using average soil degradation scores at district-level based on farmers’ perceptions; (ii) the fertilizer needs (short-term demand) at district and at national levels based on adjusted fertilizer doses; and (iii) the potential for sustainable fertilizer use.

3.1.1. Overall data generation and statistical methods used

A thorough description is made in the next sections of the methods for generating data on soil degradation, adjusted recommended fertilizer doses, fertilizer needs (short-run fertilizer demand) and the potential for sustainable fertilizer use. Descriptive statistics (sample means comparisons) were used for quantitative analysis throughout the paper. Regarding soil degradation in particular, a two-tier statistical method was used. At district-level (extension agents' perceptions) very simple calculus in Excel spreadsheets were done on the data because number of observations is lower than 20 per district. At farm-level appraisal (farmers' perceptions), the SAS software Version 8.1 was used to process and analyze the data because samples were large enough (N = 26–63 farmers per district, and N = more than 250 farmers per region. It was, therefore, possible to give the significance levels of means and correlation coefficients.

3.1.2. Method for calculating soil degradation scores

Soil degradation was measured as a proxy opposite of soil fertility, based on extension agents' and farmers' visual appraisal of the nature of the soils (respectively, at district and farm level), general state of the landscape, change in vegetation, and trends in main crops' yields.

At district level, extension field agents were requested to estimate the overall soil degradation level of agricultural lands in each sub-district under their district's agricultural authority, using the scale: 1: lowly or not degraded, 2: moderately degraded, 3: highly degraded. District senior extension officers also participated jointly in the assessment by providing corrections when necessary.[7] Average soil degradation score was then estimated as the weighted average of soil degradation levels (1, 2, 3), the weights being the number of sub-districts represented at each degradation level.[8]

At farm level, farmers in selected districts were requested to say which acreage or percentage of their total cultivable land area is degraded. This means getting soil degradation estimates on a "0–100" scale. In those districts, extension agents' estimation at district-level could thus be compared with farmers' estimation, although the latter refers mostly to cotton fields.

Then the rationale for fertilizer use could be assessed then, as to whether soil degradation status is correlated or not with fertilizer use intensity, and in the "right" direction or not. The "right" direction means relatively low fertilizer use per ha cultivated when there is little or no soil degradation, and vice-versa.

3.1.3. Method for adjusting the recommended fertilizer doses

The pan-territorial dose[9] of 200 kg/ha fertilizers (150 kg NPKSB 14-23-14-5S-1B and 50 kg urea 46% N) recommended to cotton farmers in Benin is not economical, nor is it environmentally sustainable. This study suggests an adjustment of that dose in application of the principle of wiser mineral fertilizer application in decreasing order of soil fertility level, i.e. the more the soil is fertile (or less degraded) before fertilizer application, the less the quantity of mineral fertilizer to be applied. Desirable fertilizer doses are calculated according to that principle. On the "1–3" scale of soil degradation at district level, the logic of fertilizer application proportionately to soil degradation status[10] is proposed as follows:

Desirable dose = k × (dose for potential yield)

The k coefficients depend on the soil degradation scale that is used. In this study, k is the relative degree of soil degradation at district-level and the dose for potential yield is by default taken as the current recommended dose of 200 kg/ha. Hence:

Desirable or adjusted dose = 200 × (observed absolute soil degradation level)/3.

3.1.4. Method for estimating fertilizer needs (short-run fertilizer demand)

In this paper, we estimated future fertilizer needs (quantities) at the 2008 horizon considering the desirable fertilizer doses for a wise soil fertility improvement and the likely trends in land use (cultivated areas).[11] Against that background, fertilizer needs are estimated based on the following assumptions:

(1) Average cultivated area p.a. during the “2000–2003” period, after the “1995–1999” cotton boom, is likely to be the annual cultivated area in the 5 following years (horizon 2008) if agricultural intensification takes off.[12]

(2) Desirable or adjusted dose = 200 × (observed absolute soil degradation level)/3.

(3) Maximum fertilizer diffusion rate to be expected refers to main fertilized crops (cotton, maize) and to sorghum and cowpea that are showing growing prospects for fertilizer use.[13]

(4) Estimated fertilizer needs or Demand (quantities) = (Desirable dose) × (Fertilized area) = (Desirable dose) × (Maximum expected diffusion rate) × (Average cultivated area, 2000–2003) = (2) × (3) × (1).

The diffusion rate of a technology is the percentage ratio of area on which the technology is applied to total area cultivated. The formulae (4) assume that steady fertilizer demand translates into the application of “reasonably accessible” or desirable doses adopted on a large proportion of cultivated areas according to ISFM principles. Then, the gaps between short-term needs (demand) and actual consumption could be estimated. Considering that cultivated areas increase each year proportionately to population growth, one may need to introduce the latter in the formulae. However, advocating for sustainable land use suggests a non-expansion of cultivated areas and adoption of relatively intensive production techniques.

3.1.5. Method for estimating the potential for sustainable fertilizer use

The *potential for sustainable fertilizer use* (PSFU) was estimated in this study using a systematic method based on farm-level soil degradation rate (% area degraded out of total area available to farm household) and farmers’ performance in fertilizer use (% present consumption to potential short-run demand) and other soil fertility management techniques. PSFU’s intra-regional variation was then highlighted to guide fertilizer policies. The whole estimation process and methods are presented hereafter.

The potential for sustainable agriculture is expressed as the *potential of sustainable fertilizer use (PSFU)*:

PSFU = f(soil fertility status, current fertilizer use performance, ISFM demand), where:

Soil fertility status = soil quality = f_1(inherent fertility[14], current soil degradation status, climate);

Current fertilizer use performance = f_2(ratio current/optimal dose, adoption rates[15] of recommended fertilizers, dates, and methods of application);

ISFM demand (f_3) = Average diffusion rate of ISFM technologies (fertilizer, organic matter, water and soil conservation techniques, improved seeds).

ISFM is integrated soil fertility management with recommended soil fertility-enhancing technologies. We do not know a priori the functional form of PSFU. Estimating the above complex functions requires a multidisciplinary expertise. For the purpose of simplifying PSFU estimation, let’s consider a student’s intellectual quotient and his potential of success to exams. When the student usually does not get marks closer to the maximum score in a subject matter or the whole class curriculum, due to his hereditary characteristics, we may say that he has a natural low learning capacity or a low intellectual quotient, which keeps wide the gap between his achieved score and the maximum score. On the opposite, a student with a high intellectual quotient has a small gap and enjoys a great potential of success. In general, any student’s potential of success depends on his intellectual quotient (natural ability) and the conditions of his learning environment[16] that determine his willingness to learn or his demand for learning. Therefore, we may intuitively put it simply as follows:

Potential of success = intellectual quotient × (current performance rate) × (index of learning environment)

The intellectual quotient is the hereditary factor (h); and current performance rate = 100 × (current score/maximum score). Hence:

Potential of success (%) = 100 × [h × 100 × (current score/maximum score) × (index of learning environment)]

When we consider that perception for the purpose of estimating an agricultural zone's potential of sustainable fertilizer use, we define:

h = "soil quality" = "soil fertility index" of the zone

Current score = amount of fertilizer actually used (QE)

Maximum score = fertilizer amount required to meet the needs (QE_p)

Index of fertilizer use environment = Index of ISFM technologies' use = (average ISFM diffusion rate)/100.

Therefore: PSFU (%) = 100 × [(soil fertility index) × 100 × (QE/QE_p) × (average ISFM diffusion rate)/100]

Soil fertility index = 1−(percentage rate of soil degradation/100). As mentioned earlier, this is just an indicative measure of soil fertility for the purpose of rapid socioeconomic assessments[17]. Therefore:

PSFU (%) = 100 × [1−(percentage rate of soil degradation/100)] × (QE/QE_p) × [(average ISFM diffusion rate)/100]

$$\text{PSFU}\,(\%) = [1 - (\text{percentage rate of soil degradation}/100)] \times \left(\text{QE}/\text{QE}_p\right) \times (\text{average ISFM diffusion rate}) \tag{5}$$

ISFM technologies include mineral fertilizer, organic matter, improved seeds, water, and soil conservation methods. Here, improved seeds concern only maize (second fertilized crop after cotton), as cotton is always cultivated with improved seeds. The diffusion rate reflects both the economic capacities of use and the technical skills that determine initial adoption decisions. The fertilizer amount meeting the needs (QE_p) may be: (i) the fertilizer dose to reach potential yield times the achievable crop area, using recommended soil preparation techniques; (ii) the fertilizer dose recommended by extension services times the same achievable crop area; or (iii) the desirable fertilizer dose according to appropriate ISFMtimes the achievable crop area, using current soil preparation techniques.

The achievable crop area is function of existing land tenure regime and farmers' production objectives. For a sustainable agriculture, expansion of cultivated area should be restricted to account for population growth and the consequent land occupation for non-agricultural uses (housing, nature conservation, etc.). Considering that it is difficult to estimate the "achievable crop area using recommended soil preparation techniques", we used the third option by default in the PSFU formulae, thereby approximating the quantity of fertilizer meeting the needs (QE_p) by the estimated needs (QE_b) in formulae (4) in sub-section 3.1.3.

3.2. Study area, sampling, and data collection methods

A PhD research project conducted from 2003 to 2007 on fertilizer distribution in the liberalized cotton sub-sector in Benin. It was carried out in the two main cotton-producing regions of Benin, i.e. Borgou-Alibori (BA) in the north (750–1100 mm/year; 24 inhab/km^2); average seed cotton yield around 1300 kg/ha) and Zou-Collines (ZA) in the center (900–1200 mm/year; 23–110 inhab/km^2; average seed cotton yield around 900 kg/ha). They are later referred to, respectively, as Northeast region and Central region. In both regions, fertilizer use is cotton-oriented but actually as a hidden front-cover for food crop production. However, the food security basis is weaker in the first region than the second where various food crops (maize, tubers, legumes, etc.) are regularly produced, thanks to a higher and two-season rainfall. But the regional differences in the food security situation may be minimal sometimes, e.g. during bad seasons.

A field survey was done in these regions to collect primary data on fertilizer use and farmers' evaluation of fertilizer marketing services. The present study deals with the first part of the survey. It was conducted in 29 districts of the 2 regions for a first participatory assessment of soil degradation, with a dedicated support of field extension officers. A total of 255 sub-districts covering various soil types and cropping zones over 986 617 ha cultivated were surveyed.

Then an in-depth assessment of farmers' perceptions of soil degradation and fertilizer use practices was done at the farm level with a sample of 577 farmers selected in 191 villages of 14 districts (8 in ZA and 6 in BA). The fertilizer use investigation addressed technological variables (area cultivated, area and crops fertilized, quantities of fertilizers, doses of application, intensity of fertilizer use, rate of diffusion, complementary inputs/technologies, etc.). Districts and villages were chosen purposively taking into account different levels of fertilizer use, crop production diversity and levels of soil degradation. Farmers were "randomly" chosen from lists of members of village-level cotton producers' organizations so as to get small-, medium- and large-scale farmers according to area cultivated. The resulting sample was, therefore, representative of cotton producers in the two zones.

Although the above data may appear, the situation of extensive land use, low fertilizer application and soil degradation has not improved yet.

4. Results and discussion

4.1. Cotton production systems and differential soil degradation status in Benin

In 2003–2004, cotton occupied, respectively, 51 and 32% of total area cultivated in the Borgou-Alibori and Zou-Collines regions. During the cotton boom year (1999), the first region represented about 50% of total cotton area and 45% of fertilizer consumption in the country, and the second one 30 and 33%, respectively. District-level secondary data covering all districts (29) in the 2 regions reveal a high and significant correlation coefficient ($r = 0.867$) between cotton share in total cultivated area and fertilizer use intensity over the 1999–2003 period. Farm-level data in the 14 selected districts also show a high and very significant ($p < 0.0001$) correlation ($r = 0.743$ for both regions together) between the two variables. Indeed, the fertilizer supply policy is mainly cotton-oriented as it is based on cotton area predictions and fertilizer procurement on credit. However, cotton is usually grown in various types of cotton-cereal rotations; production systems are still extensive through the slash-and-burn land clearing technique.

In the central region, about 41% of 332 570 ha cultivated were on highly degraded soils, 35% on moderately degraded, and only 24% on lowly degraded soils, so that average soil degradation score was 2.2. In the northeast region, corresponding figures are 21, 42, and 37% of 654 047 ha cultivated, and 1.9 for the average soil degradation score (Table 2). This slightly lower score may be explained by large areas of fertile lands that are still available in some districts in the north. Farmers' differential accessibility to fertilizers and the large variability in fertilizer use on food crops may also explain the differences within and between the 2 regions. In the central region, little or no fertilizer at all is

Table 2. Differential soil degradation status and fertilizer use intensity in cotton zones of Benin

Districts[a]/Regions	Area cultivated p.a. (ha)2000–2003	Number and % sub-districts per level of soil degradation[b]						Average score of soil degradation	Fertilizer use intensity (kg/ha)[c]
		1		2		3			
		N	%	*N*	%	*N*	%		
Abomey	5,325	0	0	2	29	5	71	2.7	58.1
Agbangninzoun	8,780	0	0	5	50	5	50	2.5	28.5
Bante	30,405	7	78	2	22	0	0	1.2	31.4
Bohicon	6,904	2	25	2	25	4	50	2.3	27.4
Cove	13,017	0	0	1	14	6	86	2.9	9.5
Dassa-Zoume	29,781	0	0	5	56	4	44	2.4	42.9
Djidja	29,664	7	58	2	17	3	25	1.7	99.8
Glazoue	38,770	0	0	6	60	4	40	2.4	26.2
Ouesse	60,700	2	22	2	22	5	56	2.3	10.7
Ouinhi	8,605	0	0	3	75	1	25	2.3	57.3
Save	15,552	4	50	2	25	2	25	1.8	47.4
Savalou	38,693	3	21	7	50	4	29	2.1	38.9
Zagnanado	8,747	0	0	2	33	4	67	2.7	32.8
Za-Kpota	22,782	0	0	3	37	5	63	2.6	57.0
Zogbodomey	14,845	6	55	1	9	4	36	1.8	53.3
Zou-Collines	*332,570*		*24.2*		*35.1*		*40.7*	*2.2*	*41.4*
Tchaourou	40,470	4	57	3	43	0	0	1.4	24.7
Parakou	34,539	0	0	3	100	0	0	2.0	14.9
N'Dali	29,815	2	40	2	40	1	20	1.8	36.6
Perere	27,059	3	50	2	33	1	17	1.7	23.7
Nikki	50,956	3	43	4	57	0	0	1.6	48.9
Kalale[d]	64,723							1.8	64.5
Sinende	36,680	0	0	3	25	9	75	2.8	75.4
Bembereke	52,242	7	47	6	40	2	13	1.7	59.0
Gogounou	32,017	2	14	4	29	8	57	2.4	119.3
Kandi	74,642	11	73	3	20	1	7	1.3	80.6
Banikoara	99,876	7	47	2	13	6	40	1.9	83.6
Segbana	44,862	6	43	6	43	2	14	1.7	84.8

(*Continued*)

Table 2. (*Continued*)

Districts[a]/Regions	Area cultivated p.a. (ha)2000–2003	Number and % sub-districts per level of soil degradation[b]						Average score of soil degradation	Fertilizer use intensity (kg/ha)[c]
		1		2		3			
		N	**%**	***N***	**%**	***N***	**%**		
Malanville	33,837	0	0	5	100	0	0	2.0	66.3
Karimama	32,331	0	0	4	80	1	20	2.2	18.9
Borgou-Alibori	*654,047*		*37.3*		*42.1*		*20.5*	*1.9*	*57.2*

Source: Honfoga (2007), PhD thesis, p.147.

[a]Shadowed lines indicate the districts that were selected for farm-level primary data collection.

[b]Soil degradation levels: 1 = lowly or not degraded, 2 = moderately degraded, 3 = highly degraded.

[c]Average fertilizer use intensity 2000–2003: quantity used/area cultivated.

[d]Soil degradation data could not be obtained there and the average degradation level was estimated as the mean value of surrounding districts.

Table 3. Pearson's correlation coefficients (*r*) between fertilizer use intensity and soil degradation status at district level in Benin, 2000–2003

	All districts		Selected districts	
	r	***N***	***r***	***N***
Zou-Collines	−0,340	15	−0,599	8
Borgou-Alibori	0,280	14	0,365	6
Both regions	−0,134	29	−0,273	14

Source: Honfoga (2007), PhD thesis, p. 148.

directly used on food crops. Appropriate fertilizer types are not available for food crops and access to cotton fertilizers is restricted to members of cotton producers' cooperatives.

4.2. Rationale for fertilizer use in cotton-producing zones of the study area

In contrary to the "homogenous picture" of cotton zones presented by the cotton board officials, intra-regional differences are so important (see Table 2) that it is worth checking if fertilizer use intensity is congruent with soil degradation status. Correlation coefficients calculated using district-level data are negative for the central region and positive for northeast region (Table 3). The negative relationship is apparently backward, as one would normally expect that greater amounts of fertilizers are applied per ha cultivated on degraded soils to restore fertility, and small amounts on lowly/moderately degraded soils to maintain fertility. In the reality extensive agricultural practices increase soil degradation and lead farmers to apply lower and lower amounts per ha over space. This may be explained by the fact that with little or no application of organic matter or other forms of soil amendments, highly degraded soils do not reward well fertilizer use. It seems to confirm ICRISAT (1987)'s view that such a trend is observed when soils have a low cation exchange capacity and face acidification and aluminum toxicity problems.

The concerned farmers would, therefore, reduce fertilizer use intensity when they start facing such problems. In the central region of Benin, farmers who avail large land areas usually clear new fields where soils are still fertile in order to get greater crop response to fertilizer use. In the northeast region however, the normal relationship seems to dominate (positive correlation coefficients). Yet, fertilizer is not always applied on degraded soils, as complementary soil fertility-enhancing technologies are not practiced, either by lack of resources or by ignorance. The expansion of cotton areas leads to greater fertilizer use in absolute terms but also increases soil degradation through the occupation of new fields via the slash-and-burn land clearing technique.

Farm-level primary data in the selected districts reveal that average land cultivation rate (share of cultivated area in total land area available to the household) is 68% among cotton farmers in the northeast region, and 57% in the central region. This confirms that cotton areas are expanding in the leading cotton-producing districts, especially in the northeast region where animal traction is widely adopted. Farmers' extensive land use strategy was also confirmed by the highly significant positive correlation coefficients between land cultivation rate and soil degradation rate, as declared by farmers themselves (Table 4).

Particularly in the central region, continued extensive slash-and-burn land use practices go with diminishing fertilizer use intensity over space. Five districts out of 8 show negative correlation coefficients between soil degradation rate and fertilizer use intensity at farmer-level, and the coefficients were highly significant 3 times out of 5 (Table 5).

The farm-level data show that fertilizer use intensity decreases with increasing soil degradation over space in the central region. This is alarming, provided that 76% of total cultivated area (ha) belong to moderately or highly degraded soils (see Table 4). On the contrary, the normal relationship

Table 4. Pearson's correlation coefficients between land cultivation rate and soil degradation rate[a] at farmer-level[b]

	Average land cultivation rate(%)	Average rate of soil degradation(%)	Pearson Coefficientr	*N*	Prob $r_N > \|r\|$ under $H_0: \rho = 0$[c]
Borgou-Alibori	66.9	34.3	0.102	86	0.3522
Zou-Collines	56.6	28.2	0.341*	105	0.0004
Both regions	61.3	30.9	0.248*	191	0.0005

Note: *N* = number of observations (villages).

Source: Honfoga (2007), PhD thesis, p. 150.

*1% significance level.

[a]The rate of soil degradation at farm-level is the percentage ratio of degraded fields' area to total cultivable area available to the farm household (according to farmers' own perceptions and evaluations).

[b]Farmers were interviewed in 191 selected villages and the values refer to the 2003/04 and 2004/05 crop seasons. Average village mean values were used here in order to solve the problem of missing values with some farmers.

[c]Probability that observed Pearson's correlation coefficient (*r*) is zero as hypothesized for population (ρ) and sample (r_N).

Table 5. Correlation between soil degradation rate and fertilizer use intensity at farmer-level in selected districts, 2003/2004–2004/2005 cropping seasons

Regions/ Districts	Average fertilizer use intensity (kg/ ha)	Average soil degradation rate (%)[a]	Correlation between fertilizer use intensity and soil degradation rate		
			Coefficient	*N*	Prob $r_N > \|r\|$ under $H_0: \rho = 0$[b]
Borgou-Alibori	*154.2*	*34.3*	*0.103**	*257*	*0.099*
Sinendé	140.8	42.6	0.316*	36	0.060
Bembéréké	139.7	34.4	0.155	45	0.309
Gogounou	169.6	18.8	0.114	42	0.471
Kandi	145.2	11.9	0.027	44	0.860
Banikoara	170.4	79.1	−0.366***	48	0.010
Ségbana	156.9	15.5	−0.074	42	0.638
Zou-Collines	*85.6*	*28.2*	*−0.045*	*314*	*0.422*
Dassa-Zoumè	83.3	23.0	0.126	63	0.324
Djidja	106.9	30.3	0.401***	44	0.006
Glazoué	78.0	25.6	−0.227	30	0.227
Ouessè	17.7	27.6	−0.200	32	0.273
Ouinhi	115.6	16.5	−0.391**	26	0.048
Savalou	113.0	30.6	0.309**	42	0.046
Za-Kpota	108.4	27.5	−0.394***	35	0.019
Zogbodomè	58.3	41.3	−0.154	42	0.330
Both regions	116.5	30.9	0.035	571	0.405

Note: N = number of observations (farmers).

Source: Honfoga (2007), PhD thesis, p. 151.

*10% significant level.

**5% significant level.

***1% significant level.

[a]The soil degradation rate is the percentage share of degraded soils' area in total cultivable area available to the surveyed farm households.

[b]Probability that observed Pearson's correlation coefficient (*r*) is zero as hypothesized for population (ρ) and sample (r_N).

rather dominates (4 districts out of 6) in the northeast region, thereby confirming the results obtained with district-level data, although correlation coefficients are not significant at 5% level.

Differentiation among cotton growers may explain the differences in land- and fertilizer use behavior across regions and within regions in terms of positive versus negative trends in soil fertility management. Indeed, medium class cotton growers have greater access than small-scale growers to agricultural input services when cotton market perspectives improve, especially access to credit and farm equipment. This leads to greater land clearing and fertilizer use capacity. Indeed, credit dispensation by the Cotton Inter-Professional Association (AIC) is based on land area available or cultivated. Moreover, agreements may arise in this regard between cotton ginning companies and a few farmers' organizations under particular contract farming. James and Woodhouse (2017) observed such a trend among black capitalist medium-scale sugar cane growers in Nkomazi, South Africa.

However, the situation in Banikoara—where about half of the country's cotton tonnage is achieved—supports the thesis of slash-and-burn extensive land use, with lower and lower qunatities of fertilizer per ha cultivated as soil degradation increases (correlation coefficient is negative −0,366, significant at 1% level). Some previous studies have found that soil degradation is becoming a real concern because of cotton areas' expansion in the northeast cotton belt of Benin (Alohou & Nelen, 2000; Samba Bio Tobou, 2000, p. 1).

Due to large intra-regional variations in the "soil degradation-fertilizer use" relationship with farm-level data, regional aggregate correlation was quite zero, especially in the central region. But the overall picture is that negative correlation is prevalent in the central region where food production is top priority for farmers but access to appropriate fertilizers is limited. On the contrary, it is positive correlation that dominates in the northeast region where cotton mobilizes most efforts of agricultural production.

However, considering the significance level of correlation coefficients at district-level, it is the negative relationship that reflects more the situation in the field. Cropping techniques rely so much on the slash-and-burn practice of area extension that fertilizer use intensity is less than proportionate to soil degradation rate. This is contrary to the common sense of sustainable soil fertility management. It suggests that farmers' rationale for fertilizer use in cotton-producing zones of Benin is backward. However, the perceived backwardness may be rejected, with the argument that farmers are captured into rapid social and economic transformations that affect input and output demand and supply, especially fertilizers and cotton lint in the international market. Indeed, shifts in the production, sourcing and sales strategies and technologies of transnational manufacturing, and massive new possibilities attendant on information technologies are recent persistent trends in the agrarian world (Bernstein, 2008). Watts (2012) witnessed Bernstein (1977) finding of how capital transformed agriculture regionally through different patterns of agrarian change.

In spite of these transformations and the constraints farmers are facing, the results of the present study among cotton growers in Benin suggest that unless ISFM is adopted, even higher doses of fertilizer on newly colonized cotton fields (leading to greater fertilizer use intensity) would not be enough to curb down the growing soil degradation in the Banikoara district of Benin. If appropriate mechanisms are not designed to supply fertilizers for food crops, soil degradation will continue in spite of apparently sustained fertilizer use on cotton fields. Moreover, in addition to mineral fertilizers, the adoption of other soil-fertility enhancing technologies (organic matter, soil and water conservation, improved seeds, etc.) influence fertilizer use strategies and determine a region's potential for fertilizer-based agricultural intensification. This is illustrated later after future fertilizer needs are estimated according to the method presented in Section 2.

4.3. Short-run fertilizer needs

Short-run fertilizer needs are estimated using formulae (4), and the gaps to present consumption are calculated. Then an extrapolation to the whole country is made considering current consumption patterns over space. The results show very large gaps between short-run demand and present consumption, as about 141% of the latter in the central region and 87% in the northeast region. In the first region, soils are highly degraded because agriculture is food crop-oriented with little access to appropriate fertilizers. Therefore, short-run demand is about 2 to 7 times present consumption. The opposite is observed in the second region where present consumption is closer to the needs (Table 6).

The differences between the 2 regions reflect the regional bias in the cotton-oriented fertilizer supply policy. Yet, some districts in the northeast region are also food crop-oriented and suffer from the same bias: gaps are 1–4 times present consumption. Assuming the northeast region/country ratio of fertilizer consumption in 1999 is kept, the national short-run demand is estimated to about 158,000 MT/year. Adegbidi et al. (2000) estimated the national demand in 2005 to 111,350 MT, based on a scenario deemed economically accessible to farmers (projected area reached, fertilizer dose 200 kg/ha, diffusion rate 30%). Our estimation (158,000 MT/year) rather considers a large range of desirable fertilizer doses (82–181 kg/ha)—depending on the soil degradation status—a higher average diffusion rate (about 70%) for all soil-fertility enhancing technologies, and the likely trends in land use even when the major cash crop (cotton) enjoys a price boom.

Undoubtedly, such short-run future consumption level is environmentally justified and economically accessible. It assumes that the government promotes farmers' access to credit, especially in the zones where soils are highly degraded and where commercial banks may restrict credit supply because of high production risks. If area expansion is allowed in pace with rural population growth, fertilizer demand would be about 163,500 MT/year. This estimated national consumption will become effective if sustainable soil fertility management principles are applied and if appropriate fertilizers become available for food crops (especially cereals).

The above results suggest that in order to increase fertilizer consumption towards the needs, soil fertility management and fertilizer supply policies should better promote desirable or economically accessible doses on large areas cultivated rather than pan-territorial high doses that will be adopted only by a few farmers on a limited area. Future fertilizer demand will be satisfied if food crops become fully involved in reliable commercial streams. According to Rusike, Reardon, Howard, and Kelly (2003), the green revolution in Asia was due mostly to the intensification of cereals' production rather than traditional export crops. In some West African countries, efficient domestic and regional markets, and improved socioeconomic conditions are inducing an intensive food crop production, more than traditional export crops (Breman & Debrah, 2003; Wiggins, 1995).

4.4 Potentials for sustainable fertilizer use in the area

Improved quality of natural resources, farmers' technical knowledge, economic capacity and institutional environment will be determinant to promote a sustainable fertilizer use. Increasing fertilizer consumption alone will not be enough to achieve potential crop yields if sustainable natural resource management is not implemented. In order to illustrate that assertion, the potential for sustainable fertilizer use (PSFU) or fertilizer-based agricultural intensification is calculated according to formula (5) elaborated in sub-section 3.1.4 for that purpose. The results show that both regions together have a very low PSFU (only 13.6%), compared with the maximum potential of 100%. If the central region's low PSFU (8.3%) reflects the limited availability of fertilizers for food crops, the northeast region's PSFU is also low (17.5%) in spite of its higher relative fertilizer use performance (Table 7). The overall picture reflects at least one of the following: very large gaps between fertilizer needs and present consumption, considerable soil degradation rate, and poor diffusion of complementary soil-fertility enhancing technologies. When one looks particularly at the results in individual districts, it appears that a high fertilizer use intensity does not necessarily mean a high potential for

Table 6. Estimated fertilizer needs and gaps to present consumption in cotton regions of Benin

	Average soil degradation status	Desirable fertilizer doses(kg/ha)	Maximum expected diffusion rates(%)	Annual fertilizer needs(MT)	Present annual consumption, 2000–2003(MT)	“Needs-present consumption” gaps(%)
Zou-Collines	*2.2*	*149*	*67.1*	*29,918*	*12,425*	*141*
Abomey	2.7	181	76.6	738	242	205
Agbangnizoun	2.5	167	73.7	1,079	244	342
Bante	1.2	82	58.4	1,447	847	71
Bohicon	2.3	150	80.3	832	184	353
Cove	2.9	191	38.5	956	121	691
Dassa-Zoume	2.4	163	79.0	3,835	1,254	206
Djidja	1.7	111	73.4	2,421	2,955	−18
Glazoue	2.4	160	68.6	4,259	882	383
Ouesse	2.3	156	36.7	3,471	541	541
Ouinhi	2.3	150	74.3	960	486	98
Save	1.8	117	73.4	1,332	749	78
Savalou	2.1	138	63.7	3,407	1,580	116
Zagnanado	2.7	178	68.2	1,062	268	296
Za-Kpota	2.6	175	72.0	2,870	1,298	121
Zogbodomey	1.8	121	69.4	1,249	775	61
Borgou-Alibori	***1.9***	***125***	***67.8***	***55,958***	***40,760***	***87***
Tchaourou	1.4	95	54.9	2,039	980	108
Parakou	2.0	133	54.3	2,491	511	387
N’Dali	1.8	120	65.4	2,410	1,108	117
Perere	1.7	111	70.2	2,209	656	237
Nikki	1.6	105	82.3	4,159	2,516	65
Kalale	1.8	122	77.2	5,854	4,229	38
Sinende	2.8	183	68.1	4,581	2,760	66
Bimbereke	1.7	111	74.5	4,130	3,078	34
Gogounou	2.4	162	84.0	4,266	3,865	10
Kandi	1.3	89	76.9	5,266	6,003	−12
Banikoara	1.9	129	86.7	10,952	8,473	29
Segbana	1.7	114	75.1	3,914	3,817	3
Malanville	2.0	133	55.6	2,516	2,219	13
Karimama	2.2	147	23.3	1,172	544	115

Notes: Fertilizer needs = (Desirable dose) × (Maximum expected diffusion rate) × (Average cultivated area, 2000–2003). Shadowed lines correspond to the districts selected for primary data collection.
Source: Adapted from Honfoga (2007), PhD Thesis, p.172.

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Table 7. Potentials for sustainable fertilizer use in cotton-producing zones of Benin

	Farm-level soil degradation rate(%)	Present annual fertilizer consumption(QE, MT)	Annual fertilizer needs(QE_b, MT)	Relative fertilizer use performance(100*QE/$QE_{b,}$ %)	Average diffusion rate of ISFM technologies(%)	PSFU (%)
Borgou/Alibori	**34.3**	*40,760*	*55,998*	**72.8**	*36.7*	*17.5*
Sinende	42.6	2760	4581	60.2	36.7	12.7
Bimbereke	34.4	3078	4130	74.5	37.5	18.3
Gogounou	18.8	3865	4266	90.6	36.9	27.1
Kandi	11.9	6003	5266	114.0	34.9	35.1
Banikoara	79.1	8473	10,952	77.4	30.9	5.0
Segbana	15.5	3817	3914	97.5	39.9	32.9
Zou/Collines	**28.2**	*12,425*	*29,918*	**41.5**	*27.7*	*8.3*
Dassa-Zoume	23.0	1254	3855	32.5	31.8	8.0
Djidja	30.3	2955	2421	122.1	25.5	21.7
Glazoue	25.6	882	4259	20.7	19.8	3.0
Ouesse	27.6	541	3471	15.6	9.9	1.1
Ouinhi	16.5	486	960	50.6	38.6	16.3
Savalou	30.6	1580	3407	46.4	38.3	12.3
Za-Kpota	27.5	1298	2870	45.2	41.2	13.5
Zogbodomey	41.3	775	1249	62.0	16.5	6.0
Both regions	30.9	53,185	85,916	61.9	31.8	13.6

Notes: MT = metric tons. PSFU (%) = [1−(percentage rate of soil degradation/100)] × (QE/QE_p) × (average ISFM diffusion rate).

Source: Honfoga (2007), PhD Thesis database.

Table 8. Fertilizer use intensity versus potential for sustainable fertilizer use

Cotton-producing districts	Current situation of soil fertility management	PSFU(%)
Kandi	High fertilizer use intensity on lowly degraded soils and high diffusion rate of soil fertility-enhancing technologies	35.1
Banikoara	High fertilizer use intensity on highly degraded soils and low diffusion rate of soil fertility-enhancing technologies	5.0
Glazoué	Low fertilizer use intensity on degraded soils and low diffusion rate of soil fertility-enhancing technologies	3.0
Ouessè	Low fertilizer use intensity on degraded soils and very low diffusion rate of soil fertility-enhancing technologies	1.1

Source: Honfoga (2007), PhD Thesis database.

Table 9. Comparing extension agents and farmers' perceptions of soil degradation in high cotton production districts in Benin

	Extension agents' perceptions(scale: 1–3)*	Farmers' perceptions(scale: 0–100)**
Borgou-Alibori	2.5(n = 86)	34.3(n = 257)
Zou-Collines	2.2(n = 105)	28.2(n = 314)
Both regions	2.3(n = 191)	30.9(n = 571)

Source: Honfoga (2007), PhD Thesis database.

*Soil degradation levels: 1 = lowly or not degraded, 2 = moderately degraded, 3 = highly degraded.

**Soil degradation rate is the percentage share of degraded soils' area in total cultivable area available to the surveyed farm households.

agricultural intensification if soils are highly degraded and average diffusion rate of other complementary technologies is low (See examples in Table 8).

Knowing that fertilizer supply policy in Benin targets mostly the northeast region, very few people can imagine that Banikoara, which is the leading cotton production district (with the highest fertilizer use intensity and more than half of the national cotton tonnage), has a potential of sustainable fertilizer-based intensification as low as that of Glazoué and Ouessè (central region) where fertilizer use is comparatively very low. The situation of soil fertility management is worse in the southern region where food crops are priority but are paradoxically suffering from the lack of specific fertilizers. Overall, the discriminatory cotton-oriented fertilizer policy will not promote a sustainable agricultural intensification in Benin. Therefore, from now on, fertilizer procurement policies should avoid crop or regional biases and rather aim at raising the potentials for sustainable fertilizer use in production systems. This is urgently needed, if food security is to improve significantly in Benin and elsewhere in Africa where similar trends in soil fertility management are observed. Undoubtedly, if one considers the growing international fertilizer prices, local distribution problems, and other economic constraints to the adoption of soil fertility-enhancing technologies, the costs of incorporating soil fertility management into the economic systems will be high. For example, increasing threefold the current average PSFU value in the study regions to about 40% would require far more increases in present investments. But the rewards will be large gains in productivity and sustainability, and food security over at least 1–2 decades. It is worth raising an alert about greater state budget allocation to agriculture, with special focus on farmers' support for sustainable land use, and on private sector's capacity-building for input/output market development.

4.5. Limitations of soil degradation perceptions data used in this study

Using farmers' perceptions to assess soil degradation as a proxy opposite of soil fertility was extensively documented earlier. Although this method may be criticized for its lack of accuracy—with reference to strict soil science methods whereby nutrients and organic matter contents are measured—it is useful for rapid and low-cost socio-environmental assessments of soil fertility and land

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conservation decision-making, provided that the respondents are on such a move. However, it may be right to doubt about farmers' perceptions. Indeed, the research results reported in this paper indicate that farmers think their lands are not degraded yet (giving them the reason to continue farming with low fertilizer use), whereas field extension agents think land degradation levels are quite high (Table 9). This discrepancy is an evidence of the limitation of the "perceptions" method. Nonetheless, both groups of respondents agree that land degradation is higher in the northern (with about 70% of the country's cotton production) than in the central region. If soil degradation levels, as perceived by farmers, were to be moved higher and closer to extension agents' perceptions, the present capacity or potential of the country for fertilizer-based sustainable soil fertility management would be much lower. This is a strong environmental warning that calls for a swift change in soil fertility policies, anchored on direct support to farmers with less indebtedness as Bellwood-Howard (2014) and Nyantakyi-Frimpong (2015) highlighted.

5. Conclusion

The study addressed the sustainability of fertilizer-based soil fertility management in Benin. It diagnosed the relationship between differential soil degradation status over space and fertilizer use in cotton production systems. It found that present fertilizer use practices overlook the spatial differences in soil fertility status in export-oriented cotton production systems. Evidence was provided of the backwardness of such practices that have led to a very low potential or capacity for sustainable agricultural intensification. Adjusting current fertilizer recommendations to site-specific soil conditions is urgently required to promote the sustainability of cotton production systems. A more rational fertilizer use will be critical to inducing higher land productivity while preserving the environment. Therefore, more informed fertilizer supply and use policies should be implemented, based on updated recommendations that are drawn from prevailing soil fertility status and farmers' adoption capacities. Only then could cotton growers experience a steady increase in agricultural productivity and improved net incomes.

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Notes

1. In Benin, only 10.4 kg of fertilizers were applied per ha of arable land in 2004, just slightly above the 9 kg/ha average of Sub-Saharan Africa (Honfoga, 2013).
2. Yield potential for rain-grown cotton production systems depends on soil water storage and rainfall but is about 800 kg lint/ha (Constable & Bange, 2015). This corresponds to 2388.05 kg/ha for seed cotton. The potential yield under irrigated conditions is about 4.5 times that of rain-fed cotton, but irrigated cotton is not yet grown in Benin. However, some best practice farmers in Kandi district (Northeast region) were reported to reach 3 tons/ha.
3. In Dassa-Zoumè, yields increased from 0.7 to 1.1 ton/ha (Bessou, 2013).
4. Sources: www.benininfo.com; www.panapress.com.
5. See http://www.un.org/popin/fao/centafriq/frentex3.htm.
6. In a study on the use phosphate rock in cotton and cocoa fields in Togo, three levels of intensification (current practice, fertilizer use introduction, and semi-intensive production) were distinguished with reference to the potential yield. The semi-intensive production was the most promising in terms of sustainable soil fertility management, but in the short run it does not guarantee a value/cost ratio higher than that of fertilizer use introduction (ITRA/IFDC-Africa, 1998, p. 42 et pp. 51–55). Therefore, economic factors are important in the choice of desired intensification level.
7. All the field extension agents (TSPV) who conducted this survey hold a Master's degree in agronomy, and at least 2 years of field experience in the districts investigated. District senior extension officers (RCPA) are of the same education level with greater supervisory experience.
8. Cultivable areas of these sub-districts should have been used as weights, but reliable area data were not available.
9. The doses that correspond to the potential yields of various crops are not known to extension services and farmers in Benin. The pan-territorial dose (200 kg/ha) recommended for cotton by extension services is

considered here as a default reference that reflects the potential aggregate yield in cotton-based cropping systems and the existing capacities to achieve it.

10. Breman (personal communication, October 2005) thinks that higher soil fertility levels should be targeted rather than simply replacing the nutrients lost. This is right but one should be realistic while keeping in mind the principles of soil fertility management (Table 1) and the explanations hereafter provided.
11. A more accurate assessment of needs should consider specific/appropriate fertilizers for each crop or group of crops (cotton, cereals, tubers, legumes, oilseeds, fruits, vegetables, etc.). The method used here is for a rapid appraisal of fertilizer demand.
12. Elsewhere, the likely trends in crop areas/cultivated lands would be referred to, considering recent developments in the agricultural sector.
13. The percentage share of these four crops in total cultivated area in 1999 (peak cotton boom year) is the maximum fertilizer diffusion rate to be expected, assuming that those crops respond equally to price signals to motivate fertilizer demand.
14. The nature of the parent rock of a soil determine of its inherent fertility or original suitability for agriculture.
15. The adoption rate of a technology in a region is the percentage ratio of number of farmers who adopted to the total number of farmers.
16. This includes, e.g. the socioeconomic conditions of his parents/household, cultural inclusion or adaptation of teachers, school density in the neighborhood, access to schoolmate exchange groups, presence of a public library, etc.
17. Inherent soil fertility (parent rock) and climate are ignored here.

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