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Simulating the effects of tax exemptions on fertiliser use in Benin by linking biophysical and economic models

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ABSTRACT

The sluggish increase in the area productivity of staple crops is a major factor causing increased dependence of African countries on food imports. The increased use of mineral fertiliser may dramatically improve the food balance of many countries and result in lower food prices, higher food supply and consumption, and improved food security and nutritional status. In Benin, West Africa, political measures to improve farmers' access to fertiliser are biased in favour of cotton production. This article simulates the impact of universal tax exemptions for fertiliser use on crop yields, food balances, and the use of land resources for the most important staple crops in Benin using a crop growth model and an agricultural sector model. The simulation results indicate that tax exemptions on fertiliser use could have positive effects on physical productivity and would increase food security until 2025 as compared to a baseline scenario. At the same time, the pressure on land resources would not be aggravated, so that better access to fertiliser may help to curb excessive cropland expansion in Benin.

1. Introduction

The growth of area productivity in Africa's agriculture is below the world average. Increases in production are largely achieved by expanding agricultural areas. For instance, the land area used for cereal crops increased by more than 60% between 1985 and 2005, whereas yields increased by 20% only, barely reaching 1.4 metric tons per hectare. By contrast, cereals area worldwide expanded by less than 7% during the same period, whereas average yields increased by almost 30% (FAOSTAT, 2009) to 3.3 metric tons per hectare. An important reason for this divergence in productivity is the insufficient use of fertiliser in Africa. Whereas almost 70 kg of nitrogen were applied per hectare of arable land worldwide in 2005, only 16 kg were applied in Africa (FAOSTAT, 2009). This resulted in 22 kg of nitrogen being lost annually per hectare of cultivated land (IFDC, 2003).

The problem seems to be widely acknowledged by both African governments and the international donor community (Chianu et al., 2008), and most development policy agendas include suggestions about how incentives can be created to promote small-scale farmers' increased adoption of agricultural practices that enhance the fertility of soils (Agwe et al., 2007). In particular, the case for increased use of mineral fertilisers is largely emphasised on the grounds that, among the Green Revolution technology packages, fertiliser has been responsible for an important share of agricultural productivity growth. In Asia, it contributed 50% to crop yield growth and contributed an estimated one-third to the growth of cereal output worldwide (Morris et al., 2007). Beyond its effects on agricultural productivity and food security, the 'Borlaug hypothesis' (Borlaug, 2000) claims that the use of fertiliser and other yield-increasing inputs will contribute to curbing excessive expansion of cropland, as fertiliser can be viewed as a land-saving form of technical progress. Higher productivity on existing farmland will reduce farmers' incentives to expand cultivation into forests or savannahs (Angelsen and Kaimowitz, 2001).

Opposing this view is another extreme view, according to which the promotion of increased mineral fertiliser use will result in cropland expansion. This is based on the assumption that most regions of Sub-Saharan Africa represent a 'Boserupian' environment. As long as arable land is abundantly available, farmers will not intensify farming until forests or other land reserves have almost disappeared (Boserup, 1965). As increased use of mineral fertiliser raises yields and agricultural profits, farmers will clear more forest or savannah, further increasing pressure on land resources. Which of the two predictions will dominate depends on several factors. First, even if land is abundantly available, the expansion of cropland comes at a cost, as turning forest or savannah into cropland is very labour-intensive. The opportunity costs of cultivating additional land also increase with the general scarcity of land and a rising trend in the price of low-skilled off-farm labour. On the other hand, a higher integration of subsistence

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farmers into local, national, and world markets will dampen or even prevent the price-depressing effect of local productivity improvements. Barbier and Burgess (2002) provide an extended survey of studies and models on the economics of cropland expansion, shifting cultivation, and deforestation. Careful, theory-based, empirical research is the necessary next step for designing public interventions for specific contexts (Takasaki, 2006; Timmer, 2005). Empirical studies have been conducted on the issue using cross-national samples (Angelsen and Kaimowitz, 2001); however, the number of single-country assessments has been limited due to methodological and, in particular, data availability problems (Morris et al., 2007).

The current paper offers an assessment of the promotion of fertiliser use in Benin, West Africa on cropland expansion. Biophysical simulation methods are used to assess individual crop responses to fertiliser use. Based on this, endogenous fertiliser use functions are estimated and calibrated against fertiliser use and yield data using regional (commune level) agricultural statistics. These functions are implemented within an agricultural sector model that is used to simulate crop supplies and land use patterns until 2025.

The article is organised as follows. First, the use of fertiliser in Benin as well as prices and policies are discussed. As a major result, the magnitude of regional quotas for fertiliser to which farmers have access at reduced prices and under conditions of commodity credit are estimated. Next, results of simulations on yield response to fertiliser use are presented for major food crops in Benin. From these point simulations, non-linear approximations are derived, which are used in a regionalised multi-market model for Benin's food sector (BenIMPACT). To address the policy issues at hand, fertiliser use above the regional quotas of subsidised fertiliser is calibrated to the base year of BenIMPACT on the basis of observed yields, market prices, and the physical yield functions. Thus, fertiliser use is an endogenous choice variable for farmers. After the calibration of quotas, a baseline simulation up to the year 2025 is compared to a change in fertiliser policy involving tax exemptions.

2. Fertiliser policy, use, and costs in Benin

Benin's agriculture is dominated by the production of staple crops by subsistence farms and the production of seed cotton for export. These two sectors receive different attention in terms of agricultural policy. This is especially true for programs aiming to increase fertiliser use, which are closely linked to cotton production (Adégbidi et al., 2000). As cotton accounts for roughly 90% of Benin's export earnings, policy measures in this sector have typically aimed at ensuring a constant and sufficient supply of seed cotton to the local cotton processing plants. The most important tool for stabilising cotton supply is a contract farming system within which fertiliser is supplied to individual farmers on the basis of a commodity credit scheme and at pan-territorial prices that involve tax exemptions and transport subsidies. The defining feature of this commodity credit system is that the costs for inputs delivered to cotton producers are later deducted from the cash payments for the cotton delivery to the company. The delivery of inputs and the collection of cotton produced are jointly managed by a corporatist system involving producers, cotton processors, and governmental agencies (IFDC, 2005; World Bank, 2002, 2004). The required amount of fertiliser for cotton production needs to be estimated beforehand by this corporatist system, which is why the amount of subsidised fertiliser available in Benin depends directly on how much and where cotton is planted and processed.

Economically, this policy can be classified as a fertiliser quota that is adapted annually to the expected expansion of regional cotton areas. The price for fertiliser that is sold within this quota (the 'in-quota price') is uniform across regions (pan-territorial) and also across the various types of fertilisers, regardless of differences in marketing costs and quality. This uniformity resulted in pan-territorial prices of FCFA 95 to FCFA 235 (FCFA 1000 = €1.52) per kilogram over the period of 1992–2007, with the price doubling in 1994 after the devaluation of the FCFA. Whereas this pan-territorial price is typically higher than the border prices of the various varieties of fertiliser, it is considerably lower than the prices that farmers must pay outside the fertiliser quota system (referred to as the 'over-quota' price). The pan-territorial 'in-quota' price is implicitly subsidised by not applying import duties and value added tax (VAT) and, if necessary, by subsidising import credit, transportation, and distribution among farmers. In terms of the magnitude of tax exemptions granted to fertiliser sold within the cotton system, Adégbidi et al. (2000) estimated that import duties applied to fertilisers stood at approximately 29% until 2000. From 2000 onwards, member states of the UEMOA (*Union Economique et Monétaire Ouest Africaine*), including Benin, adopted a common import duty on fertilisers of not more than 7%. The VAT applied in Benin is 18%. In addition to lifting import duties, the government may provide a variable subsidy depending on the levels of the world market prices of fertilisers to ensure the politically desired level of the pan-territorial price. From 2000 to 2004, Honfoga (2006) estimated that this subsidy amounted to 4.6% of the total cost of fertilisers imported for the cotton sector. For the agricultural season 2008–2009, it was expected to increase to 32%, which corresponds to a subsidy of 111.34 FCFA per kg. To manage costs from foregone taxes and subsidies, the pan-territorial price was lifted to 235 FCFA/kg for the agricultural season of 2007–2008 (http://www.aicbenin.org).

In contrast to prices, quantities of fertiliser used by farmers are much more difficult to monitor. According to official statistics, national consumption reached a peak of approximately 95,000 tons in 1999. However, the decline in world market prices for cotton led to stagnating cotton areas, with officially recorded fertiliser use subsequently falling to 62,000 tons in 2007. On the other hand, information on the commune level suggests that the application of fertiliser per hectare has remained stable at approximately 45 kg during the last decade, with large differences between communes. Applications of 50 kg per hectare and more are frequently recorded in the Northern and Central regions, whereas for most regions in the south, no use of the input is reported (see Table 10 in Appendix A). Unfortunately, figures reporting fertiliser use per crop are not available for this study. The International Fertiliser Development Center (IFDC) claims that the cotton sector accounts for 96% of fertiliser consumption in Benin (IFDC, 2005). As a consequence of the fertiliser quota system, there appears to be a strong link between fertiliser use that is officially recorded, and cotton area. Fig. 1 shows a close association between the share of cotton in total cropland and the use of fertilisers per hectare, using commune-level data for the period of 2001–2004.

It is, however, likely that farmers allocate portions of the fertiliser earmarked for the cotton system to other crops depending on the profitability of these crops relative to cotton. This is supported by Camara and Heinemann (2006), who claim that Benin has experienced a high growth in the use of mineral fertilisers as compared to other African countries. Even though fertiliser use outside of the cotton system may be much more expensive, farmers in regions without a fertiliser quota and no access to cheaper fertiliser might find it profitable to apply fertiliser to other crops. Surveys by Minot et al. (2000) and Adégbidi et al. (2000) indicate that maize, rice, and vegetables are the food crops that receive the largest share of fertilisers. Estimations by Adégbidi et al. (2000) suggest that the rate of application of fertiliser on maize and rice is likely in the range of 50–100 kg ha^{-1} in cotton-producing communes. In other areas of the country, the rate varies between 0 and 75 kg ha^{-1} for these crops. For cotton, a rate of

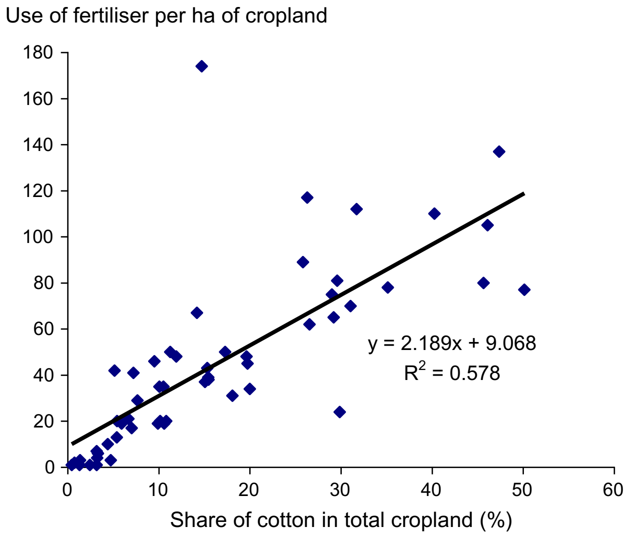

Fig. 1. The relation between the share of cotton in the regional crop rotation and regional use of fertiliser per hectare. *Source*: own calculations based on CSPR (2008) and Matthess et al. (2005).

200 kg ha^{-1} is recommended, but farmers may often apply less (within a range of 85–190 kg ha^{-1}, according to farmer surveys). Almost no fertiliser use was reported for cassava, yams, and legumes, which is plausible because of crop rotation (roots) and nitrogen fixation (legumes). To augment the fertilisation of non-cotton crops, farmers may purchase additional fertiliser outside of the cotton system, particularly in regions with small cotton areas and fertiliser quotas. To improve the productivity of staple crops in Benin, one option is to lower the costs of fertiliser on this 'free market' in a manner similar to that for cotton.

3. Modelling yield response to fertiliser application using the crop model EPIC

To estimate the amount of fertiliser applied above regional quotas, and to enable simulations of the economic effect of alternative fertiliser policies, functions that determine the physical crop yield response to fertiliser application have to be established. The choice of a suitable crop growth model was made on the basis of a review of existing simulation models that were used to assess crop productivity and fertiliser response in farming systems in Sub-Saharan Africa. Few crop growth models are able to simulate fertiliser response in low-input agriculture, which requires the consideration of fallow effects, nutrient deficiency, and water and nutrient competition in mixed cropping systems. One of the crop models that met the study's requirements is the Environmental Policy Integrated Climate model (EPIC, see Williams, 1995). EPIC is a field-scale model that calculates dry matter production, as well as soil water and nutrient balances in relation to crop management practices at a daily time step for a wide range of food crops. With respect to growth limitations, the model takes into account the following factors: (1) temperature, (2) water, (3) nutrients, (N, P, and K), (4) oxygen deficiency in the root zone and (5) salt stress. The model was calibrated with a multi-location approach in the sub-humid savannah zone of West Africa using data from station and farm fertiliser experiments (Gaiser et al., 2009; Srivastava and Gaiser, 2010). To incorporate different soil and weather conditions in Benin, the model was linked to the Soil and Land Resources Information System (SLISYS) for the Oueme river basin (Gaiser et al., 2006). SLISYS-Oueme was created to provide data about soils, climate and terrain conditions in the Republic of Benin. For this study, the soil information in the database was extracted from the soil association map of Benin (1:200,000) (Viennot, 1976; Faure, 1977, adapted by Hiepe, 2008). Observed climate information was obtained from 14 meteorological stations.

To estimate crop yields as a function of fertiliser application at the regional scale, the Upper Oueme basin was subdivided into 2550 crop response units (LUSAC: Land Use-Soil Association-Climate unit), which are quasi-homogenous with respect to land use, soil and climate. EPIC calculates the crop yield for each LUSAC unit. The result was then aggregated to the commune level according to the area coverage of each LUSAC. Simulations with increasing amounts of NPK and urea were carried out at nitrogen application rates of 0, 25, 50, 75, 100, 200 and 300 kg N ha^{-1} for all crops with a combination of two fertiliser types: NPK mineral fertiliser (14-23-14) and urea containing 45% N. The application of the two mineral fertilisers differed according to the timing and quantities specified in Table 1. The first date of application (NPK fertiliser) was assumed to be at planting, whereas the second application (urea) depended on the requirements of each crop. To avoid the emergence of phosphorus and potassium deficits at N-application rates beyond 100 kg N ha^{-1}, the amount of NPK was doubled from 100 kg N ha^{-1} onwards. As shown by Srivastava and Gaiser (2010), crop yields in the upper Oueme basin are nutrient-limited. Once nutrient requirements are satisfied, water becomes the limiting factor, which is fully taken into account by the model.

The outputs of the simulations for the different N application rates were used to establish one yield response function for each crop. The yield response functions were then normalised to the ratio of increase with respect to the control (yield without application of nitrogen fertiliser) to integrate them into the economic model BenIMPACT (see Section 4.2). The quadratic function (see Eq. (1)) is

$$y^{sim}/y^{bas} = \beta_1 + \beta_2 x + \beta_3 x^2 \qquad (1)$$

with y denoting the base (without N-application) and simulated crop yields, and x representing the application of N per hectare in tons. An example of such a quadratic approximation is presented in Fig. 4. The parameters of the quadratic yield functions are presented in Table 2. The constants (β_1) were all estimated to be close to 1 and are thus not reported.

When considering the low fertiliser use in Benin (Section 2), it is evident that agricultural production is situated at the lower end of most of the response curves. For cotton, for example, nitrogen application rates are presently 20–30 kg ha^{-1} a^{-1} (MAEP, 2008). However, the maximum yield would be reached at 150–200 kg N ha^{-1} a^{-1}. This figure is confirmed by several field trials on experimental stations and under farmer-managed conditions (RCF, 1989; Cretenet, 1993). However, caution should be applied to the maintenance of soil organic matter and micro-nutrient supply, particularly for highly weathered soils in the South of Benin (Gaiser et al., 1999). If a linear yield increase is assumed, the marginal productivity of 1 kg of nitrogen is 33 kg for cotton,

Table 1
Mode of fertiliser application on cotton, maize and rice in the model calculations.

	NPK 14-23-14		Urea		
N hg ha^{-1}	kg ha^{-1}	netN	kg ha^{-1}	netN	Sum NetN
25	178	25	1	0	25
50	178	25	55	25	50
75	178	25	108	50	75
100	356	50	108	50	100
200	356	50	326	150	200
300	356	50	500	230	280

Table 2
Coefficients of the quadratic crop yield functions for N-application.

	Quadratic coefficient (β_3)	Linear coefficient (β_2)
Maize	−176.27	32.77
Cotton	−95.17	31.66
Cassava	−195.58	35.20
Rice	−171.30	24.72
Peanuts	−125.90	21.76
Sorghum	−63.70	9.79
Yams	−612.33	44.68

27 kg for maize and 15 kg for rice, assuming that local varieties are used. Thus, there is considerable potential for increasing production with even a moderate utilisation of mineral fertilisers and, in particular, nitrogenous fertilisers (Pieri, 1989; Akonde et al., 1997; Würth et al., 2000).

4. Economic evaluation of policies for fertiliser use in Benin

4.1. The simulation model

Scenario simulations of the impact of fertiliser use on food markets in Benin were carried out with BenIMPACT (Benin Integrated Modelling System for Policy Analysis, Climate and Technology Change), which is a modelling system aimed at land-use simulations within the IMPETUS project. BenIMPACT belongs to a class of so-called bio-economic models that are designed for the simultaneous modelling and simulation of the biophysical and economic processes in regional farming systems (Holden and Shiferaw, 2004). These numerical models are mainly based on both linear and non-linear mathematical programming methods that simulate individual farms or aggregate farm sectors within regional economies (see Hazell and Norton, 1985; Janssen and Van Ittersum, 2007). The distinctive feature of bio-economic models is that they capture the mutual feedback processes of human decisions and natural processes by incorporating endogenous productivity functions for natural resources, such as the impact of management decisions (e.g., use of fertiliser, conservation measures) on agronomic and ecological processes (e.g., yield response, or the formation of organic matter in soils). Barbier and Bergeron (2001) used a recursive-dynamic model for a small river basin in Honduras with a 5-year planning horizon. As a biophysical component, yield response was simulated using the EPIC-model. Barbier and Hazell (2000) concentrated on the interaction between croppers and transhumant herders in a village in Niger. They took the influence of risk of drought on a farmer's decisions explicitly into account. In their study, modelling the productivity of fallow and savannahs as pasture for livestock as a function of grazing intensity complements endogenous productivity of cropland. Similar models were used by Okumu et al. (2004) and Holden and Shiferaw (2004). Aspects of decline and collapse have been managed by researchers investigating so-called 'poverty-traps' using bio-economic simulation models (see Barrett, 2003). This is because the interaction of resource degradation and human development can take varying paths.

BenIMPACT is a bio-economic farm sector model that covers the total area of Benin with a physical yield function and endogenous use of fertiliser resting on the assumption of profit maximisation by farmers. It is a partial equilibrium model that covers crop commodities (yams, cassava, maize, sorghum, rice, peanut, niebe, and cotton) and animal products (cattle, sheep, goats, pigs, chickens). Spatially, Benin is divided into 26 regions that represent regional markets linked by trade flows. BenIMPACT also simulates supply and demand of neighbouring countries (Nigeria, Niger, Burkina Faso, and Togo) in a simplified manner, whereas the world markets for tradable commodities are assumed to be indefinitely elastic. As to its time dimension, BenIMPACT is designed in a recursive-dynamic fashion to produce medium- and long-term projections up to the year 2025. Commodity supply is represented by regional programming models for each region. The crop mix is calibrated using Positive Mathematical Programming. Commodity demand per capita is fixed for the urban population, whereas rural household demand (involving food and leisure time) is a function of household income and commodity prices (Jansson, 2005). BenIMPACT is designed as a farm-household model for the rural population, meaning that decisions regarding production and consumption are made simultaneously. The main link between production and consumption decisions is labour time allocation: available labour time resources can be used for on-farm labour, off-farm labour, and leisure. Whereas on-farm and off-farm labour generate income, leisure is treated as a consumer good that generates utility. The price of labour time (in the model, an average wage rate for farm labour) is also the price of leisure which is considered a consumer good. If wages increase (decrease), more (less) available labour time will be spent on on-farm and off-farm labour and less (more) on leisure.

Cropland, as the second important production factor, also carries opportunity costs. In most programming models, positive shadow prices for land (serving as a yardstick for the farmers' willingness to pay for rented land) will emerge only when total cropland used is equal to the total available cropland. In Benin, however, available land resources are much larger than total cropland. BenIMPACT therefore uses a land price function estimated by Kuhn et al. (2007) that ensures that opportunity costs of land use increase with increasing regional scarcity of cropland (i.e., cropland expansion) and with higher population density, whereas the agricultural marginality of land in a region is negatively correlated with the costs of land. Increasing land prices (e.g., due to cropland expansion) thus provide a simultaneous negative feedback to the expansion of cropland.

The model is encoded in GAMS, a common modelling and optimisation software. Data sources are official statistics of Benin, FAO country statistics, World Bank, FAPRI, and own field surveys. Input data for the supply module comprise regional land endowments, a seasonal cropping calendar, crop and animal yields, crop area and animal herd sizes, regional and international commodity and factor prices, labour time requirements for farm production, and labour endowments of rural households. For commodity demand, the regional population numbers and growth rates, and the demand structure for food consumption are used. The most important driving factors over time are regional trends in population growth, labour supply, food demand, low-skill wage levels, and per capita income. A simultaneous solution of supply and demand is achieved by formulating the sector model as an MCP (mixed complementarity problem). Model output includes regional crop mix and livestock numbers, overall land use changes in the course of the simulation period, demand quantities, prices and trade flows. A detailed algebraic description of the structure of BenIMPACT can be found in Gruber and Kuhn (2008) and is available online.

4.2. Endogenising fertiliser use

To simulate the impact of changes in fertiliser policy on cropping patterns and commodity markets in Benin, the use of fertiliser was defined as a decision variable. The economic rationale of farmers to use fertiliser depends on the crop yield response to fertiliser, represented by the estimated quadratic yield response function. The final step necessary to implement the endogenous yield functions into BenIMPACT was to calibrate crop-specific use of fertiliser for the base year. This was achieved by simultaneously choosing profit-maximising levels of N-application x_i and 'base yields' y_i^b as (i.e., yields that would materialise without the use of fertiliser). These levels must satisfy the first-order-condition for the use of NPK fertiliser with an N-content of *c* (index *i* omitted in formula, see Eq. (2)). The N-content *c* in a bundle of NPK and Urea is assumed to be 25% on average.

$$\underbrace{(\overline{p^{PT}} + p^{Q})/\bar{c}}_{\text{marginal costs}} \geq \underbrace{y^{bas}\overline{p \cdot \beta_2} + 2 \cdot y^{bas} \cdot \overline{p \cdot \beta_3} \cdot x}_{\text{marginal revenues}} \perp \ x \tag{2}$$

The inequality must be interpreted such that fertiliser will be used only if marginal revenues (output price *p* multiplied by marginal yield per hectare) from N-application equal the marginal costs of fertiliser use. The marginal costs consist of the pan-territorial price of NPK fertiliser (p^{PT}) plus a regional quota rent (p^{Q}) that depends on the amount (quota) of tax-reduced fertiliser available in the regions as a result of the cotton management policy in Benin. The quota is defined in the following equation:

$$\overline{X^{Q}} + X^{OQ} \geq X^{U} \perp p^{Q} \tag{3}$$

with the quota rent p^{Q} being complementary to this quantitative restriction. The regional fertiliser quotas X^{Q} were estimated on the basis of the linear regression function depicted in Fig. 1 above. Fertiliser use above the regional quota (X^{OQ}) is only profitable if the quota rent has been exhausted, i.e., the quota rent has reached its maximum, which is the difference between the regional farm-gate price p^{R} and the pan-territorial price p^{PT} that is charged for fertiliser used within the quota (see Eq. (4)). The difference between p^{R} and p^{PT} consists of tax rates (customs and VAT) and a marketing margin of 25% plus transport costs to the region of destination.

$$\overline{p^{R}} - \overline{p^{PT}} \geq p^{Q} \perp X^{OQ} \tag{4}$$

In the calibration process, Eqs. (1)–(4) represent the calibration model that is solved with y^{sim} as the observed (and, therefore, fixed) regional crop yields in the base year. The results of the calibration process are shown in Table 3. In some southern regions, where there is almost no cotton production (Mono, Oueme, and Atlantique), quotas are very low and farm-gate prices equal the pan-territorial price plus the maximum quota rent.

These results show that the tax exemption for fertiliser for cotton production lowers farm-gate prices, particularly in the North of Benin. In Alibori, fertiliser costs would be more than 13% higher than under the quota regime. For all of Benin, the estimated use of fertiliser exceeds the sum of estimated regional quotas by almost one-quarter. The estimated fertiliser use above the regional quotas may not have been recorded as 'official' imports and thus does not appear in official statistics.

5. Scenario simulations of tax exemptions for NPK fertiliser

5.1. Scenario design

It has been shown that an appropriate use of fertiliser in Sub-Saharan Africa could tremendously increase crop yields in rainfed agriculture. Our scenarios assume that fertiliser use in Benin is constrained by taxation through border and domestic taxes. To demonstrate the long-term effects of tax exemptions for fertiliser (corresponding to an indirect subsidisation of fertiliser use) on land use expansion, farm production, and food markets in Benin, counterfactual simulations have been carried out, covering the period between the year 2000 (the base year of BenIMPACT) and 2025. The *baseline scenario* assumes that the *policy regime after 2000 is continued* throughout the simulation period, with fertiliser quotas moving in line with regional cotton areas. The *counterfactual scenario* considers that the *tax exemptions* granted to fertiliser for cotton production are made universal to all fertiliser used. Therefore, from 2010 onwards, fertiliser prices will not contain customs duties and VAT and quotas for fertiliser would be abandoned together with subsidies on transport and marketing. Both scenarios contain the reduction of import duties from 29% to 7% from 2005 onwards.

As for the driving factors common to both scenarios, the most important is regional population growth. The spatial pattern of projected population growth does not show hotspots of increase in urban areas, but rather in regions that combine abundant land reserves and a supportive climate for cropping, mostly located in the centre of the country. Rural population growth is the main driver of increased regional farmland expansion as it increases the regional pool of farm labour resources. In addition to population growth, it is assumed that the real income per capita grows at 1% per year and real wages (i.e., farm labour opportunity costs) for low-skilled labour at 0.5% per year.

5.2. Results for the farm sector

The description of the results begins with Table 4 that compares the development of crop yields due to different paths of fertiliser use between the scenarios. Due to the fact that fertiliser is only applicable to cereals and cotton, it is not surprising that only maize and, to a lesser extent, rice exhibit a significantly positive trend in the baseline scenario, whereas cotton productivity would continue its recent stagnating trend (Table 4). Under the tax-exemption scenario, yields for these three crops would increase substantially, particularly for maize.

Fertiliser use per area unit in individual crops and in total develops quite differently in the two scenarios. Table 5 shows national averages of fertiliser use for individual crops, whereas the maps in Fig. 2 compare total regional use across scenarios.

Table 3
Estimated regional NPK fertiliser quotas, use, farm-gate prices, and quota rents in the base year (2000).

	'Fertiliser quota' in metric tonnes	Fertiliser use in metric tonnes	Over-quota use in %	Quota rent	Pan-territorial price (190 FCFA) plus quota rent in FCFA/kg
Alibori	28,566	28,591	25	180	370
Borgou	21,872	23,850	1978	160	350
Atakora	13,327	13,327		164	354
Donga	6041	12,896	6855	146	336
Zou	6305	7344	1039	140	330
Collines	5198	5735	537	138	328
Couffo	4576	5398	822	125	315
Plateau	2532	8297	5765	141	331
Mono	224	345	121	133	323
Oueme	110	1338	1228	129	319
Atlantique	100	2583	2483	132	322
Benin total	88,851	109,704	20,853	147	337

Table 4
Yield trends in the scenarios (percent increase from 2000 levels).

Year	Baseline for 2025			Effect of tax exemptions on fertiliser use		
	2005	2015	2025	2005	2015	2025
Rice	7.3	7.9	8.8	7.3	12.3	13.0
Maize	1.3	25.5	27.2	1.3	54.9	56.4
Cotton	−0.1	1.4	0.2	−0.1	13.0	12.0

For crops, increases in fertiliser use correspond to the yield increases shown in Table 5. The regional distribution of changes shows that without policy change, use will not change significantly as compared to the base year. The baseline scenario exhibits slight decreases in the North caused by declining relative profitability of cotton production, whereas there are minor improvements in the South. National use per hectare is projected to increase by only 2.5%, on average, over the entire period. If tax exemptions were universal, fertiliser use would increase substantially, particularly in southern regions where quotas of subsidised fertiliser are small.

5.3. Results for agricultural supply and food markets

As Fig. 3 illustrates, the impact of the described productivity gains leads to increased area used to grow maize and cotton on the national level. Furthermore, planted areas not only increase for crops with higher yields in the counterfactual scenario, there are also slight increases yams, peanuts, and pulses as compared to the baseline scenario. It is important to note that productivity gains do not trigger expansion in crop areas as compared to the base year. Even in the counterfactual scenario, the areas of fertilised crops expand less than the non-fertilised staple crops of yams and sorghum (Fig. 4).

Changes in production result from changes in crop yields, which differ substantially between the two scenarios, and crop areas, which deviate much less. Consequently, production increases can be observed in crops for which the highest yield increases have been found – those with a better yield response to fertiliser use (see Table 6).

Table 5
Crop-specific use of fertiliser (NPK) in $\text{kg}\ \textbf{ha}^{-1}$ in the two scenarios.

Year	Base year	Baseline scenario	Effect of tax exemptions on fertiliser use
	2000	2025	2025
Maize local	18.4	55.8	112.9
Maize improved	56.7	90.6	142.1
Rice	111.8	147.2	172.0
Cotton	256.1	254.3	325.6

From the perspective of national food security, emerging future surpluses or deficits are an interesting aspect of the simulation results (Table 7). In the base year, there were nationwide deficits for rice, sorghum and pulses, and moderate surpluses for the remaining crops as a share of production. Under the baseline scenario, deficits are likely to widen, whereas surpluses diminish or even become deficits. This relatively pessimistic scenario is plausible as yield gains will be moderate (with the exception of maize), whereas population pressure and land scarcity will continue to increase. The scenario with tax exemptions for fertiliser shows that deficits for most products would not be much smaller as than those in the baseline scenario, with the important exception of maize, for which surpluses would increase to more than 50% of domestic use.

5.4. Results for land use, resource costs, and public revenues

Given its rapidly increasing population, the issue of land resource use is crucial for Benin's food situation. As long as productivity gains in the farm sector remain small and off-farm employment opportunities are not sufficient to absorb the surplus of family labour in rural areas, expanding crop area is among the few remaining options for rural households to sustain a minimum income level and food production for subsistence. On the other hand, land resources for cropping purposes are limited. The

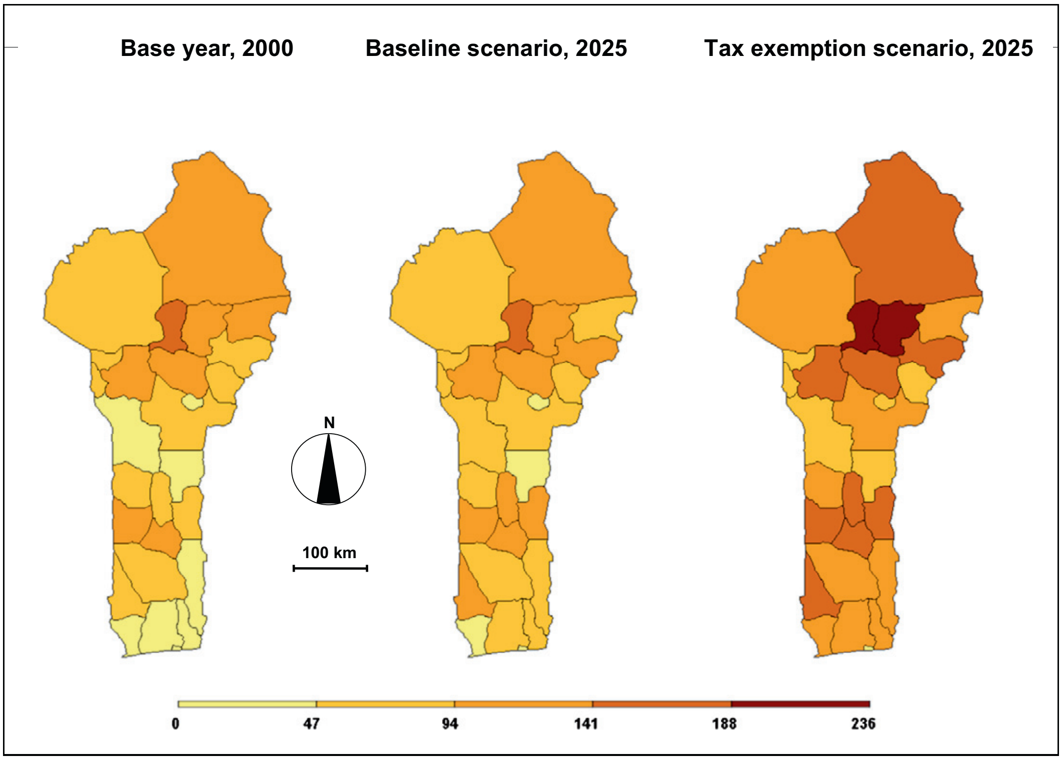

Fig. 2. Simulation results of regional use of fertiliser (in kg per hectare).

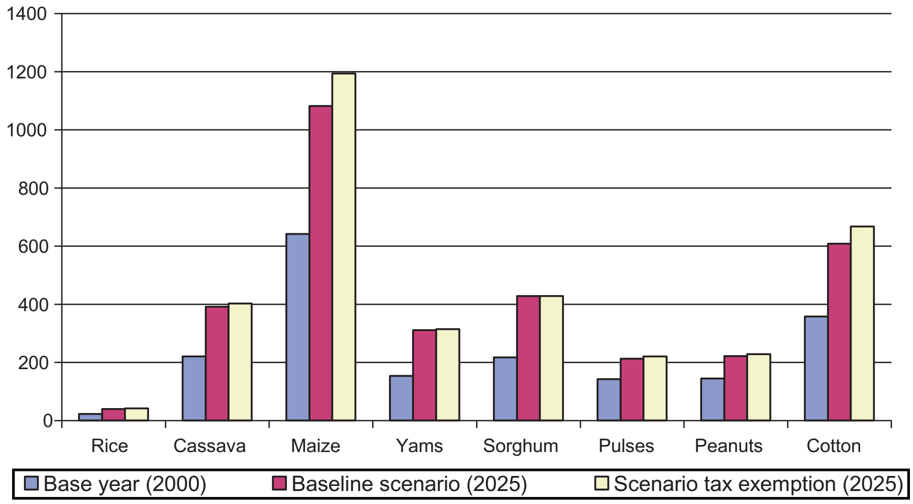

Fig. 3. Crop areas in Benin in the base year and in the three scenarios, 1000 ha.

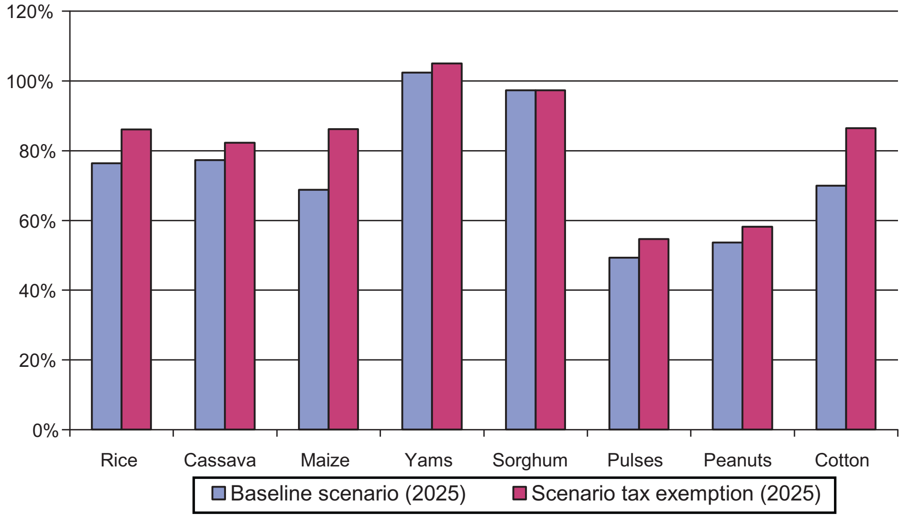

Fig. 4. Increase of crop areas as compared to the base year in %.

Table 6
Production net of losses – (1000 t) for all regions of Benin.

Year	Base year 2000	Baseline scenario 2025	Tax exemptions 2025
Rice	26.5	50.8	55.7
Cassava	1218.7	2144.4	2207.8
Maize	465.4	999.0	1354.5
Yams	940.9	1876.4	1902.3
Sorghum	140.8	280.6	280.5
Pulses	67.3	101.5	105.1
Peanuts	112.2	175.6	180.5
Cotton	374.6	637.8	781.6

southern regions of the country in particular have already been suffering from land scarcity during the last two decades. Another aspect of land scarcity is soil degradation, which will worsen as more marginal land is cultivated and fallow periods reduced within the crop rotation. The use of fertiliser may help Benin spare some of its land resources by increasing and preserving the natural productivity of cropping areas.

However, the impact of productivity gains through the use of fertiliser is not necessarily suited to curb cropland expansion. From a microeconomic perspective, land use expansion is the result of two countervailing effects: farmers will increase crop area as long as the marginal profitability gains from the cropping activity exceed opportunity costs of labour and land. These opportunity costs will also rise with land use expansion. Fertiliser use, particularly under the 'tax exemption' scenario, will make some crops more profitable. It is therefore not surprising that cropland expands more in the 'tax exemption' scenario than in the baseline scenario (Table 8). However, increases are only modest as increasing land tenure prices and wage rates curb cropland expansion by farm households. In a more closed food economy, as in land-locked countries, productivity gains may even lead to less overall use of land and labour as dropping output prices would lead farmers to reduce crop areas. Under the particular conditions in Benin, it is likely that cheaper fertiliser would lead to only a modest increase in land use as compared to the baseline situation, whereas food availability would improve significantly.

In the scenarios, national cropland use will increase annually by approximately 2.3% (base run) and 2.5% (tax scenario) over the entire simulation period. Both figures are significantly lower than rural population growth, which is assumed to slightly exceed 3% on average. The increase in the opportunity costs of land is much

Table 7
Surplus or deficit for all regions of Benin (in 1000 t and in percent of domestic use (in italics)).

	Base year 2000		Baseline scenario, 2025		Tax exemptions, 2025	
	In 1000 t	% of use	In 1000 t	% of use	In 1000 t	% of use
Rice	−150.0	*−85.0*	−295.3	*−85.3*	−288.7	*−83.8*
Cassava	162.7	*15.4*	21.9	*1.0*	53.4	*2.5*
Maize	81.2	*21.1*	138.3	*16.1*	491.9	*57.0*
Yams	28.0	*3.1*	−112.5	*−5.7*	−101.2	*−5.1*
Sorghum	−34.1	*−19.5*	−134.9	*−32.5*	−133.7	*−32.3*
Pulses	−6.8	*−9.1*	−103.9	*−50.6*	−99.9	*−48.7*
Peanuts	27.0	*31.8*	−36.1	*−17.1*	−30.4	*−14.4*

higher in the scenario involving tax exemptions, explaining a major part the result that cropland expansion does not significantly differ between the two scenarios.

The described positive effects of tax exemptions for fertiliser use suggest that it might be useful for the state budget to forego some customs and VAT revenues for the sake of improving food supply. The value of tax exemptions might be roughly 13 billion FCFA per year in 2025 (tax revenues in billion FCFA in 2025 (base run) = projected price of 230 FCFA per kg × 227.400 MT of total use × [1 + 0.18 VAT + 0.07 customs tariffs]). To put this amount into perspective, let us assume that the central government budget would increase by the combined population (2.31) and economic (1.28) growth rates that have been used in the simulations. This would lead to central government revenues of 824 FCFA billion in 2025 (from 281 billion in 2000), which is a conservative assumption as central government revenues grew at more than 8% annually between 2001 and 2006. The share of tax exemptions for fertiliser in total government revenues would amount to roughly 1.6% in 2025. This is a much smaller fiscal sacrifice than, for instance, the fertiliser subsidisation programme of Malawi which reduced prices to 25% of the prevailing market prices. The fiscal costs of the programme amounted to 5.2% of the national budget in 2006–2007 when international fertiliser prices were still moderate. In the course of the commodity price crisis of 2008 the fiscal costs of the subsidy programme more than doubled due to increased world market prices for fertiliser, putting a major burden on Malawi's taxpayers (Minot and Benson, 2009).

5.5. Sensitivity analyses and discussion

To illustrate the influence of various driving forces and variables on cropland expansion, scatterplots matching regional cropland expansion with rural population growth and the increase of land prices are shown in Fig. 5.

There is a clear positive correlation between cropland expansion and rural population growth, the latter being the most important driver of farm labour supply. The correlation between cropland expansion and the increase in land prices (the opportunity costs of regional farmland) is negative (as expected), as higher land costs discourage farmland expansion. Higher increases in land prices are most likely to occur in regions where fewer land resources are available. However, the correlation between cropland expansion and increases in land prices is less significant than that between cropland expansion and rural population growth. Thus, whereas growing land scarcity has a unidirectional effect on cropland expansion, rural population growth has a large positive effect through rising farm labour supply. However, this population growth also has a negative effect as (using the land price function in BenIMPACT) land prices increase both with higher regional land scarcity and higher population density, the latter of which is driven by rural population growth.

Table 8
Results for land and fertiliser use in Benin across scenarios.

Year	Base year 2000	Baseline scenario 2025	Tax exemptions 2025
Total cropland use (1000 ha)	1416.9	2482.2	2625.0
Cropland use, change to 2000 (%)		75.2	85.3
Cropland use by rural population (ha/capita)	0.57	0.44	0.46
Opportunity costs of cropland (1000 FCFA ha^{-1})	11.3	14.9	16.9
Use of NPK fertiliser (kg per ha)	77.4	91.6	139.1
NPK use, change to 2000 (%)		18.3	79.7

Moreover, the base run was made subject to two sensitivity experiments to demonstrate the impact of selected driving factors and assumptions. The sensitivity runs address the assumption inherent in the model that cropland expansion over time is to a large extent driven by the supply and costs of labour. Rural population increase primarily drives cropland expansion by increasing farm labour supply. Exogenous population growth rates applied in the model were extrapolated from observed regional population growth trends of the last two decades, differentiating between rural and total population growth. The growth of the urban population was then calculated as a residual. Projected rural population growth is smaller than both urban and total population growth on the national level. However, there are pronounced differences between regions, depending on whether a region was urbanising, as most regions in the South, or subject to rural–rural in- or out-migration, as many regions in the Centre and North of the country. The first sensitivity analysis (SA-I) assumes that rural population growth will be equal to the total (and thus urban) population growth for all regions. As overall population growth in the base run is higher than rural population growth, SA-I is expected to result in a slower expansion of total cropland over time due to reduced farm labour supply.

Another important driver in BenIMPACT is the exogenous growth of wage rates for low-skilled labour (off-farm labour in the model), which is the assumed anchor wage rate for farm labour. In the absence of time series data on low-skill wages and real incomes, the base run of BenIMPACT assumes that real wage rates of low-skilled workers increase at half the rate of real income of all households. Behind this assumption is the observation that, in the course of economic growth, low-skill wages tend to grow less than overall income, the latter of which includes income increases of skilled labour and upper-income households. If real low-skill wages increase at the same rate as real income (i.e., more than assumed in the base run), the opportunity costs of on-farm labour would increase faster over time. This would lead *ceteris paribus* to less labour use in farming and thus a slower expansion of cropland. The second sensitivity analysis (SA-II) assumes equal increase in real wages and incomes.

In the SA-I analysis, a slightly higher overall growth in rural population in most regions results in a faster expansion of cropland, as the supply of farm labour increases slightly (Table 9). The difference in the use of fertiliser to the initial base run is negligible. This result, however, does not suggest that the model results are insensitive to rural population growth. This is evident

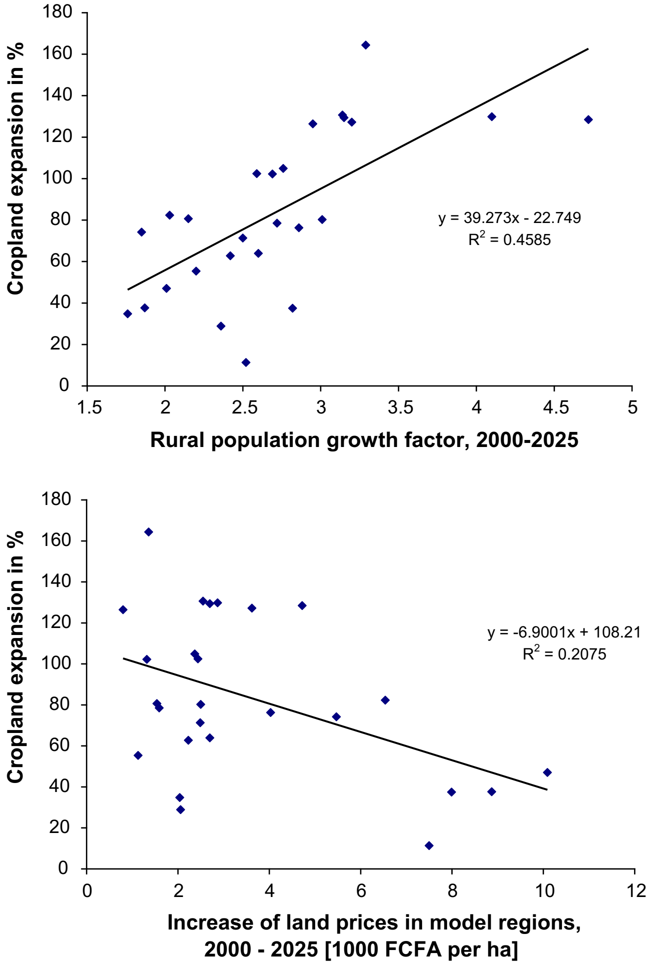

Fig. 5. Simulated increase in crop areas by 2025 as compared to important driving factors for the BenIMPACT model regions (base run results): rural population growth (linked to higher farm labour supply), increase in land prices (higher values indicate growing scarcity of cropland).

from the result for swiftly urbanising regions, which, in the base run, have fast urban growth and slow rural population growth. For instance, cropland use in the department Atlantique, which contains the suburban settlements of Cotonou, increases by a factor of 1.54 in the base run when the rural population increases by 1.36. The sensitivity analysis assumes a rural population growth of 2.8 and an expansion of cropland by the factor of 2.27. The result for Atlantique confirms the strong positive effect of rural population growth on cropland expansion, even though the marginal effect seems to be below 1, as indicated by Fig. 5.

The results of the second sensitivity analysis (SA-II) are of interest for a different reason. Exogenous wage growth in the economy causes farm labour to be more expensive and thus makes cropping and cropland expansion less attractive. Therefore, the rural labour pool will be attracted to off-farm labour. Apart from the expected negative effect of this on cropland expansion, more expensive labour leads to a higher level of fertiliser use even without tax breaks. This result demonstrates the mechanism of indirect substitution of input factors at work in the model and illustrates the Boserupian prediction that labour scarcity makes the use of modern inputs more profitable. It highlights the potential of non-agricultural growth to deliver incentives to the agricultural sector to become more technically efficient.

Other exogenous drivers such as world market prices for outputs and inputs are largely held constant over the simulation period (at least beyond 2005), but their change may heavily influence the results of simulations. Moreover, the fixedness of prices is related to the assumption of functioning international trade and price arbitrage. In an open economy such as Benin, international food and fertiliser price levels largely determine domestic price levels as long as arbitrage through trade is possible. These international prices are volatile in the short run, but tend to be relatively stable in the longer run. A long-term increase or decrease in the international food price level would produce macro-economic repercussions and adaptations such as adjustments of the exchange rate or the balance-of-payments, rising domestic inflation, and real wage and income decreases. This macro-economic adjustment would, in sum, work against the pure world price change effect on consumption and production, but modelling such macro-economic effects in a partial equilibrium model like the one used in this study is not possible.

An important implication of the assumption of relatively free trade is that regional surpluses or deficits for most commodities can be exported or imported, respectively, without major technical (e.g., congestion of transport facilities), political (border measures), or macro-economic (e.g., national balance-of-payments) problems. A macro-economic problem resulting from the ‘tradability assumption’ is that a country may not earn sufficient foreign exchange by exporting goods to pay for necessary food imports. On the other hand, thriving exports of food or non-food may increase the exchange rate and thus may make imports cheaper and further exports less profitable. In the case of Benin, the exchange rate of the Franc CFA is pegged to the Euro. This means that increased imports or exports will not have a direct negative feedback on the prices of traded goods through endogenous adjustment of the market exchange rate. Thus, the invariability of export and import prices to trade volumes in BenIMPACT approximates reality.

Due to the short period for which model results can be compared to real developments and the lack of available data on driving factors such as weather events during the validation period, the scope for validation of BenIMPACT based on ex-post comparisons is limited. To assess the validity of the scenario simulations, the projected land use up to the year 2005 in the base run may be compared to the observed increase in arable land between 1999/2000 and 2004/2005. Annual cropland expansion during this period was estimated at 1.5% by Beninese official sources (regional agricultural statistics) and at 2.9% by FAOSTAT (2009). BenIMPACT estimated an annual increase of national cropland of 1.4% from 2000 to 2005. This closely resembles national statistics and shows that land use expansion lags behind population growth, at least as long as off-farm job opportunities are sufficiently available for descendants of farming households.

Generally, the scope to statistically assess the validity of modelling systems that rely, at best, on short time series, such as BenIMPACT, is rather limited. The fact that the base year was chosen five years earlier than the most recently available data on cropland use makes some limited numerical validation possible. However, there are no specific data on weather events that influenced crop yields, area, and production during the 2000–2005 period. The influence of several other driving forces and assumptions was illustrated above. Sensitivity analyses for exogenous driving factors make sense when (a) long-term trends of these driving factors are uncertain to a major extent and (b) varying the driving factors for a sensitivity analysis will not, from a theoretical point of view, influence other driving factors or violate basic assumptions of the model.

Beyond driving factors, the specific structure of BenIMPACT certainly implies some limitations. For instance, risk is not taken into consideration, even though it is known that the high local uncertainty about rainfall in Sub-Saharan Africa makes the use of expensive inputs such as fertilisers economically hazardous for

Table 9
Sensitivity analyses on rural population growth and increase of real wages, results for 2025.

	Baseline scenario	SA-I: rural pop. growth	SA-II: wage growth
Total cropland use (1000 ha)	2482.20	2536.71	2097.37
Cropland use, change to 2000 (%)	75.19	79.03	48.03
Cropland use by rural population (ha/capita)	0.44	0.41	0.39
Opportunity costs of land (1000 FCFA ha^{-1})	14.90	17.27	13.48
Use of NPK fertiliser (kg per ha)	91.59	91.87	98.55
NPK use, change to 2000 (%)	18.29	18.65	27.29

SA-I: rural population growth in region = total regional population growth, base run assumptions. SA-II: wage growth is equal to growth of real income (1% p.a.), base run assumptions.

small farmers with quite limited liquidity (Yanggen et al., 1998, pp. 3–4). In pronounced contrast to temperate zones, fertiliser use in tropical Africa may thus increase the financial risk of farmers rather than decreasing it. The risk of harvest failure could be addressed by detailed local case studies on the link between volatile rainfall and harvest failure and on the related financial losses of farmers using fertiliser as compared to those not using fertiliser. Moreover, attitudes to the risk of crop failure by farmers would have to be estimated in surveys, which was beyond the scope of this study.

6. Conclusions

The simulation results suggest that tax exemption might induce an increased use of fertiliser and thus improve agricultural productivity in Benin. Given the projected population trends, Benin will need to improve crop yields to manage the limits of land availability and soil fertility. The simulations show that there is a considerable potential to increase crop productivity through the rational application of mineral fertilisers. Expanding the areas where external nutrients are added will help to rein in accelerating soil degradation through nutrient mining. The positive effect of fertiliser application on crop yields may be dampened by climate change, particularly if annual rainfall were to decrease. However, regardless of climate change, water efficiency would be higher with than without additional nutrient supply. Food supply could be improved tremendously without a significant increase in land use and subsequent loss of natural habitat.

These promising results are conservative estimates for several reasons. First, both the yield and food market simulations focused on the effect of fertiliser containing nitrogen. For that reason and due to the fact that fertiliser use could not be observed empirically for some important food crops (roots/tubers, legumes), these crops were excluded from fertilisation in the BenIMPACT simulations. However, even if fertiliser is not directly applied to roots and tubers, they benefit from fertiliser applied to other crops in different years of the cropping cycle, as most nutrients (particularly P and K, but also less fugitive N-formulations) will be stored in the soil beyond the current vegetation period. Moreover, even though legumes do not require additional mineral nitrogen, which is why NPK application to them would be wasteful, they could benefit from fertilisation with other nutrients such as P and K. The precise reasons why certain crops do not appear to receive mineral fertiliser despite a plausible need can only be determined in more detailed field surveys. In the case of sorghum, response to fertiliser as simulated by EPIC was too low to allow for economical fertiliser use, but advanced varieties might display a better yield response.

To improve the effectiveness and profitability of fertiliser use, it is not sufficient to make fertiliser available. Particularly if this

Table 10
Application of fertiliser (kg ha^{-1} cultivated) per commune in Benin, 1996–1999 and 2001–2004. *Sources*: Adégbidi et al. (2000), for the period1996–1999. CSPR (2008), for the period 2001–2007. MAEP (2005), for the period 2001–2004.

<less than 10 kg ha^{-1}				10 and less than 50 kg ha^{-1}				50 and less than 100 kg ha^{-1}				100 kg ha^{-1} and more			
1996–1999		2001–2004		1996–1999		2001–2004		1996–1999		2001–2004		1996–1999		2001–2004	
Abomey-Calavi	0	Abomey-Calavi	0	Lokossa	11	Glazoué	10	Zagnanado	50	Tanguiéta	50	Gogounou	109	Banikoara	105
Allada	0	Allada	0	Agbangnizoun	14	Parakou	13	Malanville	54	N'Dali	50	Sinendé	113	Sègbana	110
Kpomassè	0	Kpomassè	0	Djougou	14	Karimama	17	Klouékanmè	54	Malanville	62	Aplahoué	120	Kandi	112
Tori-Bossito	0	Tori-Bossito	0	Karimama	15	Bantè	19	Cobly	55	Kalalé	65	Bembèrèkè	120	Cobly	117
Zè	0	Zè	0	Ouèssè	17	Zagnanado	19	Pèrèrè	58	Matéri	67	Copargo	155	Gogounou	137
Toffo	0	Toffo	0	Bassila	19	Tchaourou	19	Ouinhi	62	Bembèrèkè	70			Copargo	174
Ouidah	0	Ouidah	0	Covè	20	Ouaké	20	Kouandé	68	Kouandé	75				
So-Ava	0	So-Ava	0	Natitingou	22	Agbangnizoun	20	Kérou	69	Sinendé	77				
Grand-Popo	0	Houéyogbé	0	Tanguiéta	23	Bohicon	20	Kandi	71	Pehunco	78				
Adjarra	0	Athiémé	0	Toucountouna	23	Natitingou	21	Nikki	73	Kérou	80				
Akpro-Missérété	0	Bopa	0	Bohicon	25	Djougou	24	Glazoué	73	Aplahoué	81				
Avrankou	0	Comé	0	Matéri	28	Savalou	29	Banikoara	73	Djidja	89				
Aguégués	0	Grand-Popo	0	Toviklin	31	Abomey	31	Savè	75						
Dangbo	0	Adjarra	0	Parakou	32	Ouinhi	34	Savalou	75						
Sèmè-Kpodji	0	Akpro-Missérété	0	Ouaké	34	Klouékanmè	35	Za-kpota	76						
Ifangni	0	Avrankou	0	Tchaourou	35	Toucountouna	35	Bantè	77						
Sakété	0			Djakotomey	42			Pehunco	79						
Adjohoun	0	Adjohoun	0	Dogbo	42	Dogbo	37	N'Dali	79						
Houéyogbé	0	Aguégués	0	Zogbodomey	46	Savè	38	Djidja	82						
Bopa	0	Dangbo	0	Abomey	49	Zogbodomey	39	Sègbana	86						
Comé	0	Sèmè-Kpodji	0			Boukoumbé	41	Dassa-Zoumè	95						
Adja-Ouèrè	0	Ifangni	0			Bassila	42	Kalalé	99						
Athiémé	2	Sakété	0			Dassa-Zoumè	43								
Pobè	2	Adja-Ouèrè	0			Nikki	45								
Boukoumbé	3	Pobè	1			Pèrèrè	46								
Lalo	3	Bonou	2			Za-kpota	48								
Bonou	7	Lalo	3			Djakotomey	48								
Kétou	8	Kétou	3												
		Covè	4												
		Ouèssè	6												
		Toviklin	7												

involves subsidies in the form of public expenditures, such support policies quickly become fiscally and economically unsustainable. Other obstacles to expanding the food supply must also be identified, particularly with respect to the cost of credit, transport, and marketing. These latter policy areas are not specific to the agricultural sector and, therefore, improvements will directly benefit many other economic activities. To prevent the 'Boserupian' outcome of spurring cropland expansion, improved access for farmers to intensification inputs might be complemented by laws or community agreements that preserve the remaining forests and savannahs. An important advantage of making mineral fertilisers more accessible is that this can facilitate such agreements. A key message here is that scarce public investment resources can be judiciously targeted to enforce a *win–win* outcome, but this requires careful empirical assessment to better predict when and how farmers will respond to soil fertility problems and government interventions (Scherr, 1999).

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Appendix A. Appendix

See Table 10.

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