## Economic impacts of soil fertility management research in West Africa

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### Abstract

This paper assesses the potential economic impacts of balanced nutrient management systems technology options: BNMS-manure, which combines inorganic fertilizer and organic manure, and BNMS-rotation, which is maize–soybean rotation, in maize-based systems in the northern Guinea savanna areas of Nigeria, Ghana, Togo and Benin. The economic surplus analysis suggested that BNMS-manure research and extension could achieve returns ranging from 17 to 25% and a maximum adoption of 24 to 48%, for the conservative and base scenario respectively; and that BNMS-rotation research and extension could achieve returns ranging from 35 to 43% and a maximum adoption of 20 to 40%, for the conservative and base scenario respectively. Our results were consistent with earlier economic analyses which showed that BNMS-rotation was more productive, profitable and acceptable to farmers than BNMS-manure. It may be difficult to achieve large-scale adoption of BNMS-manure because the increases in yields are smaller and markets for manure are missing.

**Keywords:** balanced nutrient management systems; BNMS-manure; BNMS-rotation; economic surplus; northern Guinea savanna; West Africa

*Cet article évalue les impacts économiques potentiels des options technologiques des systèmes de gestion équilibrée des nutriments (BNMS en anglais) : fumier-BNMS, qui allie engrais*

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*inorganique et fumier organique, et rotation-BNMS qui consiste en une rotation maïs-soja dans les systèmes à base de maïs dans les zones de la savane nord guinéenne (NGS en anglais) du Nigéria, du Ghana, du Togo et du Bénin. L'analyse du surplus économique a suggeré que la recherche et la vulgarisation concernant le fumier-BNMS pourraient obtenir des retours situés entre 17 et 25% et une adoption maximale de 24 à 48%, de manière respective pour le scénario conservateur et de base ; et la recherche et la vulgarisation concernant la rotation-BNMS pourraient obtenir des retours situés entre 35 et 43% et une adoption maximale de 20 à 40%, de manière respective pour le scénario conservateur et de base. Nos résultats ont concordé avec les premières analyses économiques qui avaient révélé que la rotation-BNMS était plus productive, plus profitable et plus acceptable pour les fermiers que le fumier-BNMS. Réaliser une adoption à grande échelle du fumier-BNMS peut se révéler difficile parce que les augmentations de la production sont plus faibles et parce qu'il manquent de marchés pour le fumier.*

***Mots-clés :*** *systèmes de gestion équilibrée des nutriments ; fumier-BNMS ; rotation-BNMS ; surplus économique ; la savane nord guinéenne (NGS en anglais) ; Afrique de l'Ouest*

## 1. Introduction

In 2000, as part of a major effort to address soil fertility decline in West Africa, a project on balanced nutrient management systems was launched in the northern Guinea savanna of Nigeria. The BNMS project was a collaborative effort between the International Institute of Tropical Agriculture and the Katholieke Universiteit Leuven. Its aim was to improve food security and incomes for farming communities in maize-based farming systems in the moist savanna and humid forest zones of West Africa by using integrated soil nutrient management systems. The project's major technology options are BNMS-manure (inorganic fertilizer and organic manure combined) and BNMS-rotation (maize rotated with soybean). Of the various soil fertility management options the project has developed and tested, these two have emerged as breakthroughs.

The combined use of organic and inorganic inputs saves about 50% of the cost of inorganic fertilizer on its own, and maize–soybean rotation is efficient because these crops use less of the available phosphorous than other grains and herbaceous legumes, which have a more efficient mechanism for extracting phosphorous from the soil than other crops (Vanlauwe et al., 2001). These two technological packages, BNMS-manure and BNMS-rotation, were tested and promoted in northern Nigeria along with the Sasakawa-Global (SG2000) package, which involves increased use of inorganic fertilizer. The SG2000 option uses hybrid seeds, proper plant density, and fertilizer rates that are quite high for the region (136 kg nitrogen, 20 kg phosphorus, and 37 kg potassium per ha).

Extensive economic analysis of the on-farm experiments showed that the BNMS technology options are profitable (Wallys, 2003; Ugbabe et al., 2007). Akinola (2008) tracked the uptake and impact pathways and found evidence of significant farm-level economic benefits from adoption of BNMS technologies. The aim of the present study was therefore to assess the potential economic impacts of these technologies in West Africa, with the aim of guiding further investments in research and extension. Section 2 that follows presents the data and explains the methods of research evaluation, Section 3 discusses the results, and Section 4 sums up and draws some conclusions.

## 2. Data and methods

*2.1 Study area and data*

The first farmer-managed BNMS on-farm trials were done in 2000 by the IITA (International Institute of Tropical Agriculture) in collaboration with the IAR (Institute of Agricultural Research, Zaria) and SG2000.[1] The trials (both demonstration and adaptation) were done in the northern Guinea savanna (NGS)[2] of Kaduna State, northern Nigeria, in three extension zones involving nine participating villages (see Figure 1): four in Maygana zone (Kaya, Danayamaka, Fatika and Galadimawa), three in Lere zone (Krosha, Kayarda and Kadiri Garo), and two in Birni Gwari zone (Kufana and Buruku). This study used on-farm experimental data as well as survey data collected in 2005 from a random sample of 400 households in these nine villages. The survey data enabled the researchers to track the rate and pathway of adoption of BNMS options as well as perceived constraints to adoption since the initial dissemination of these options in 2000. In addition, we interviewed BNMS researchers to gain expert opinions on technical aspects of the BNMS technologies. Baseline data assembled in 1997 also provided points of reference for the surveyed villages (Manyong et al., 2001).

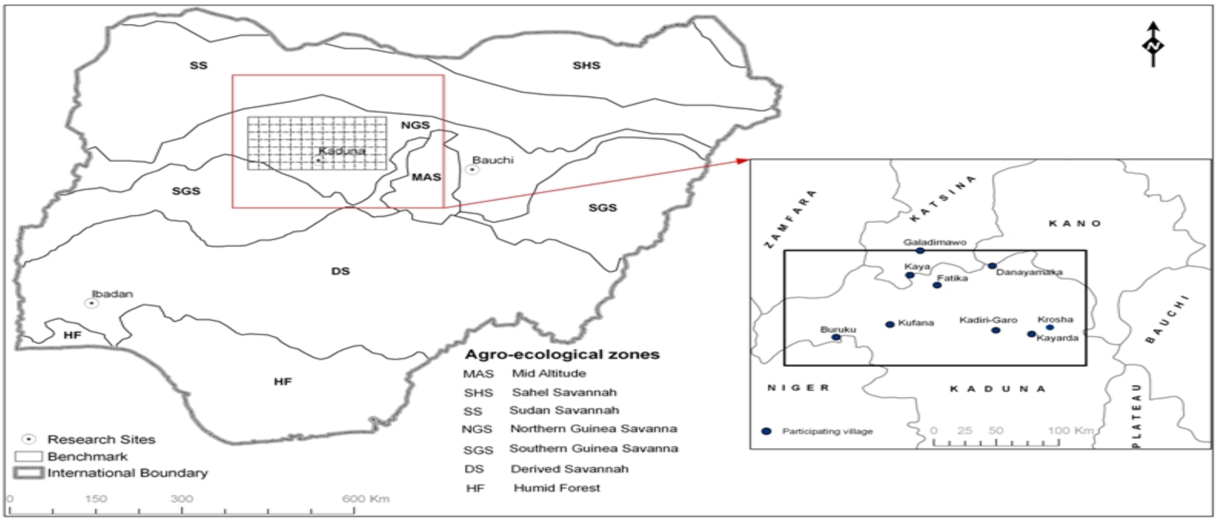


**Figure 1: Northern Guinea savanna benchmark and participating villages**

In each of the demonstration trials there were four randomized blocks – farmer practice, SG2000 strategy, BNMS-manure and BNMS-rotation (Table 1). 'Farmer practice' means the typical

[1] SG 2000 is the joint program of the Sasakawa Africa Association and Global 2000.
[2] Northern Guinea savanna is a kind of savanna common to several West African countries.

farmer practice in the area involving continuous maize cultivation; 'BNMS-manure' means using animal manure in combination with reduced fertilizer, i.e. less than would normally be used; 'BNMS-rotation' means planting soybean in the first year and maize with a little fertilizer in the same plot in the second year; and 'SG2000' means using high levels of inorganic fertilizer as well as recommended agronomic practices such as plant spacing.

**Table 1: Integrated soil fertility management options tested in northern Nigeria**

| Treatment | Year 1 | | Year 2 | |
|---|---|---|---|---|
| | **Crop** | **Input** | **Crop** | **Input** |
| Farmer practice | Hybrid maize | Farmer choice | Hybrid maize | Farmer choice |
| SG2000 | Hybrid maize | 9 bags of NPK 20:10:10 + 2 bags of urea | Hybrid maize | 9 bags of NPK 20:10:10 + 2 bags of urea |
| BNMS-manure | Hybrid maize | 6 tons of animal manure; 4 bags of NPK 20:10:10 + 2 bags of urea | Hybrid maize | 6 tons of animal manure; 4 bags of NPK 20:10:10 + 2 bags of urea |
| BNMS-rotation | Soybean TGx1448-2E | No fertilizer | Hybrid maize | 4 bags of NPK 20:10:10 + 2 bags of urea |

*Source:* IITA & KU-Leuven (2003)

*2.2 Methods*

To assess the potential economic benefits from adoption of BNMS technologies, we

1) estimated the yield gains and the unit production cost reduction,
2) defined the socioeconomic domains of maize production for extrapolation to the NGS of West Africa,
3) examined the adoption pathway, and
4) used an economic surplus model and information from the first three steps, along with secondary data, to evaluate the potential economic impacts of BNMS research.

*Yield gains and unit cost reduction*

Farmer-managed demonstration trials were initiated in 2000 in northern Nigeria by the IITA in collaboration with the IAR and SG2000. These trials were conducted in the nine villages by 26 farmers in 2002 and 20 farmers in 2003 (Kolawole et al., 2007). The results are shown in Table 2.

The demonstration trials compared three improved systems (SG2000 package; BNMS-manure and BNMS-rotation) with the farmers' own practice. The experimental layout consisted of a randomized block design with the farmers' fields as replicates (blocks). All the farmers used the same hybrid maize seeds, the same late-maturing soybean variety (TGx 1448-2E) and the same plant density (53,000 plants/ha). The cost-benefit analysis presented in Table 2 shows that over the two-year cycle the gross margins and the benefit : cost ratios were highest for BNMS-rotation and lowest for the farmers' practice, and the three improved systems all outperformed the farmers' practice. If the cost of manure is not estimated at its opportunity cost, BNMS-manure ranks second after BNMS-rotation.

**Table 2: Partial budget analysis of the demonstration trials conducted during 2002–2003**

| | Farmer practice (maize/maize) | SG2000 (maize/maize) | BNMS-manure (maize/maize) | BNMS-rotation (soybean/maize) |
|---|---|---|---|---|
| **First year of cycle (2002; costs and benefits actualized to 2003)** | | | | |
| Crop in 2002 | Maize | Maize | Maize | Soybean |
| Number of farmers | 25 | 26 | 26 | 26 |
| Average yield (kg/ha) | 2140 | 3106 | 3224 | 1474 |
| Adjusted yield (kg/ha) | 2033 | 2950 | 3062 | 1400 |
| Field price (naira/kg) | 22.53 | 22.53 | 22.53 | 38.88 |
| Gross field benefits (naira/ha) | 45811 | 66482 | 69004 | 54438 |
| Total variable cost (naira/ha) | 34197 | 40987 | 48611 | 17085 |
| Gross margin (naira/ha) | 11614 | 25495 | 20393 | 37353 |
| **Second year of cycle (2003)** | | | | |
| Crop in 2003 | Maize | Maize | Maize | Maize |
| Number of farmers | 18 | 20 | 20 | 17 |
| Average yield (kg/ha) | 1774 | 2511 | 2774 | 3065 |
| Adjusted yield (kg/ha) | 1685 | 2385 | 2636 | 2911 |
| Field price (naira/kg) | 17.15 | 17.15 | 17.15 | 17.15 |
| Gross field benefits (naira/ha) | 28906 | 40903 | 45203 | 49930 |
| Total variable cost (naira/ha) | 28100 | 30249 | 36837 | 27174 |
| Gross margin (naira/ha) | 806 | 10653 | 8366 | 22756 |
| **Average 2002–2003 (weighted average, with # of farmers each year as weights; costs and benefits actualized to 2003)** | | | | |
| Gross field benefits (naira/ha) | 38734 | 55361 | 58655 | 52656 |
| Total variable costs (naira/ha) | 31645 | 36319 | 43492 | 21074 |
| Gross margin (naira/ha) | 7090 | 19042 | 15164 | 31582 |
| Benefit : cost ratio | 1.22 | 1.47 | 1.36 | 2.50 |

*Note:* Exchange rate in 2003: IUS$ = 130 naira
*Source:* Kolawole et al. (2007)

Using the on-farm trial data presented in Table 2, estimates of the yield gain and unit cost reduction effects of the BNMS technologies can be derived as follows: (1) the average maize yield for adopters of BNMS-rotation was 3.07 t/ha, an increase of about 57% over the farmer practice yield of 1.96 t/ha, (2) the average maize yield for BNMS-manure was 3 ton/ha, an increase of about 53% over the farmer practice yield of 1.96 t/ha, (3) the unit variable cost of maize production for the farmer practice was US$124/t, but US$112/t for adopters of BNMS-manure and US$53/t for BNMS-rotation, (4) gross margins averaged about US$117/ha for BNMS-manure and US$243/ha for BNMS-rotation, an income gain of more than 47% over the US$55/ha for farmer practice, (5) BNMS-manure achieves a proportional unit cost reduction of 11% (i.e. $K_1$=0.11) relative to the farmer practice, and (6) BNMS-rotation achieves a proportional unit cost reduction of 59% (i.e. $K_2$=0.59) relative to the farmer practice (see Table 3).

**Table 3: Maize yield gains and unit cost reduction under different BNMS technology options**

| Technology | Yield (t/ha) | Cost (US$/ha) | Unit cost (US$/t) | Unit cost reduction (US$/t) | Unit cost reduction ( as a proportion of maize price) |
|---|---|---|---|---|---|
| Farmer practice | 1.96 | 243 | 124 | - | - |
| BNMS-manure | 3.00 | 335 | 111 | 13 | 0.11 |
| BNMS-rotation | 3.07 | 162 | 53 | 71 | 0.59 |

*Source:* Calculated using data in Table 2

*Socioeconomic domains for maize production in West Africa*

Agricultural production in the NGS of West Africa is driven primarily by the demand created by an increase in farming households' requirements or by an increase in opportunities for marketing agricultural products. The two sources of demand result in two broadly divergent evolutionary pathways of land-use intensification – population-driven and market-driven. These two pathways, along with the availability of land, which depends on whether the land frontier has been reached, have produced four agricultural systems here: (1) *population-driven systems in the land expansion phase* (PE), where the household need for food determines the level of production as population density increases; (2) *population-driven systems in the land intensification phase* (PI), where the land frontier has been reached and land-use intensification now goes beyond the point at which natural fallow could restore soil fertility; (3) *market-driven systems in the land expansion phase* (ME), with access to input and output markets where marketing opportunities determine farmers' choice of technologies; and (4) *market-driven systems in the land intensification phase* (MI), where the land frontier has been reached and farmers make significant efforts to increase their investment in improving and maintaining land productivity (Weber et al., 1996).

The following calculations were made for the land in the NGS of West Africa. An estimated 17% of agricultural land is in PE, while 26% and 17% have reached an early and advanced stage of PI, respectively (Manyong et al., 1994). On the other hand, about 15% and 24% of agricultural land is in the early and advanced stages of MI respectively, while only 1% of agricultural land is in ME. Since ME is negligible, the area of land under cultivation is concentrated in PE, PI and MI. However, the contribution of maize to total crop production is 21% for PE, 36% for MI and negligible for PI (Weber et al., 1996). In the analysis of potential economic benefits, therefore, PE and MI were identified as the major domains for maize production. The cultivated land area is 28.5 million ha (Manyong et al., 1994). The PE domain accounts for 17% of the total cultivated land, with maize taking up 21%. The MI domain, on the other hand, accounts for 39% of the total cultivated land, with maize taking up 36% (Weber et al., 1996). The maize area in each domain was derived as the product of (1) total land area, (2) the share of each domain in the total cultivated land, and (3) the share of maize in the total cultivated land in each domain. The total maize area was estimated at 4.82 million ha. (The maize area in the PE domain was derived as 28.5 million ha × 0.17 × 0.21 = 1.02 million ha, and the maize area in the MI domain was derived as 28.5 million ha × 0.37 × 0.36 = 3.8 million ha).

The analysis focused on four West African countries – Nigeria, Ghana, Togo and Benin – and required data on total maize production in the NGS of each of these. For the analysis, the countries' average maize yields were obtained from the FAOSTAT database for the period 1997–2004: 1.16 t/ha for Nigeria, 1.49 t/ha for Ghana, 1.13 t/ha for Togo and 1.13 t/ha for Benin. The maize production of each country was estimated as the product of the country's yield and its maize area in the NGS. The domain-specific maize area in the NGS of each country was estimated as the product of (1) total land area in the NGS, (2) the share of each domain in total cultivated land in the NGS, and (3) the share of maize in the total cultivated land in each domain. Country-specific land area in the NGS was estimated as the product of the total cultivated land in each country and the share of the NGS in the total cultivated land in each country, which was obtained from the IITA GIS laboratory – 30% for Nigeria, 7.5% for Ghana, 8% for Togo and 7.5% for Benin. The total maize production for each country was estimated as the sum of maize production across the two domains, PE and MI, in each country – about 1.8 million tons for Nigeria, 569,000 tons for Ghana, 277,000 tons for Togo and 431,000 tons for Benin.

*The adoption pathway*

Household survey data were used to project the adoption patterns of BNMS technologies over time. Adoption started in 2001 and nearly 10% of the sample households in the BNMS villages adopted one or other of the BNMS technologies in 2002. Adoption picked up between 2003 and 2004 and by the end of 2004 37% had adopted BNMS-rotation and 46% BNMS-manure. By the end of 2005, about 40% had adopted BNMS-rotation and 48% BNMS-manure. The household survey data on adoption rates were used to extrapolate the ceiling adoption rates that can be expected across the entire NGS of West Africa. Since the household survey was undertaken in an area where adoption had occurred and was occurring, the percentage of farmers who had already adopted BNMS-manure and BNMS-rotation in 2005 was assumed to be the ceiling rate of adoption – 48% for BNMS-manure and 40% for BNMS-rotation. However, it was assumed that in the larger West Africa the ceiling rate of adoption of these technologies would only be reached in 15 years, as opposed to the five years it took the project villages in northern Nigeria to reach this ceiling. In other words, it would take the larger West Africa about three years to achieve the rate of adoption that the project villages achieved in one year. The observed adoption rates in northern Nigeria from 2001 to 2005 and the assumed adoption lag for West Africa were used to estimate the parameters of the logistic function needed for predicting adoption rates in West Africa from 2007 to 2030, as follows

$$A_t = \frac{C}{1+e^{-(a+bt)}} \qquad (1)$$

where $A_t$ is the adoption of a given BNMS technology in year $t$, $C$ is the adoption ceiling for the respective BNMS technology, $b$ is the rate of adoption, and $a$ is the constant term. The adoption pathway for BNMS technology options was predicted using the following logistic function that was estimated using the survey data

$$A_t = \frac{48}{(1+e^{(3.49-0.55t)})} \quad \text{for adoption of BNMS-manure} \qquad (2)$$

$$A_t = \frac{40}{(1+e^{(3.24-0.48t)})} \quad \text{for the adoption of BNMS-rotation} \qquad (3)$$

Figure 2 shows the expected adoption pathway for BNMS technologies in the NGS of West Africa. Adoption of these technologies is expected to reach its ceiling and stabilize in a period of 15 years of extension and dissemination.

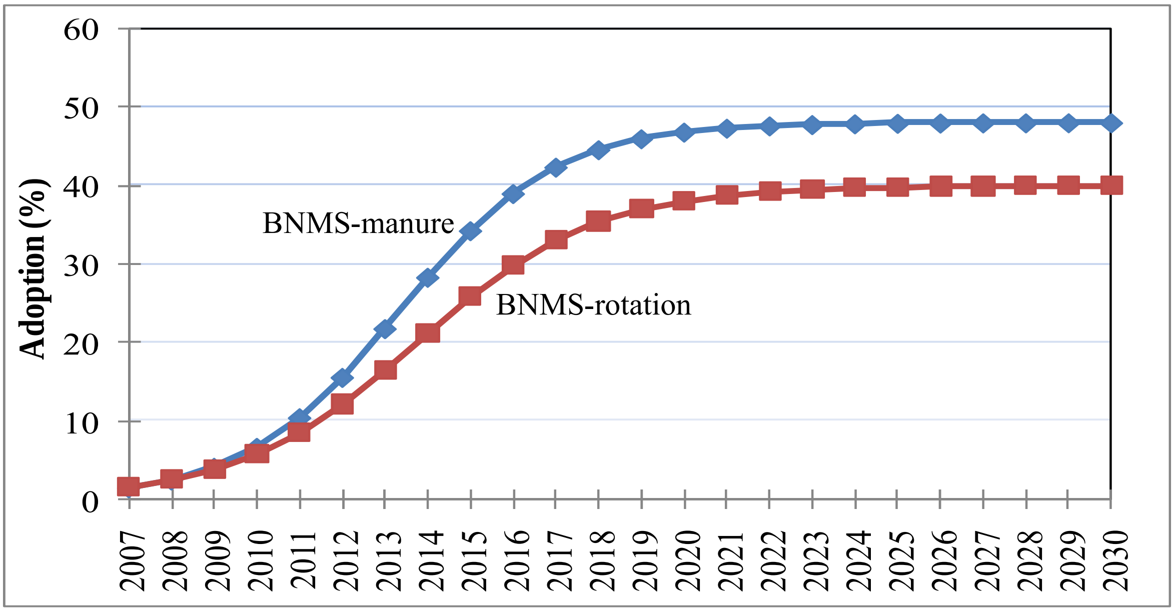


**Figure 2: Projected adoption of BNMS technologies in West Africa**
*Source:* Authors' computation

*Supply shift*

The unit cost reduction as a proportion of product price discussed earlier represents the maximum supply shift (*K*) – i.e. given 100% adoption – and translates into the actual annual supply shift ($K_t$) when multiplied by technology adoption at time *t* ($A_t$). That is, the annual supply shift is the product of cost reduction per ton of output as a proportion of product price (*K*) and technology adoption at time *t* ($A_t$). Indeed, the standard supply-and-demand diagram demonstrating shifts in the supply curve due to adoption of a new technology represents research benefits for one year. A successful research investment will yield benefits over a number of years. As the level of adoption increases, there will be further shifts in the supply curve, and corresponding changes in benefits.

*Estimating research benefits*

The potential benefits of a technical intervention can be measured ex ante as well as ex post. Following Alston et al. (1995), a number of studies have applied the economic surplus model to estimate research benefits (Kristjanson et al., 2002; Okike, 2002; Bantilan et al., 2005). The essence of the economic surplus model is that an improved technology, such as BNMS, reduces the cost of production of each kilogram of output, leading to a shift in the supply curve to the right, an increase in the quantities supplied and traded, and a drop in prices in a competitive market. When this happens, although the selling price is reduced, smallholder producers may benefit from the reduced production costs and from selling larger quantities of maize produced at these lower costs, while consumers benefit from lower purchase prices. Two scenarios are always presented: the closed and the open economy models.

Assuming a closed economy model implies that the adoption of BNMS-manure and BNMS-rotation increases the supply of maize. This study used a partial equilibrium, comparative static model of a closed and an open economy and the simple case of linear supply and demand with parallel shifts. A review of research benefits by Alston et al. (1995) revealed that most studies have used the assumption of linear supply and demand curve. Alston et al. (1995) argue that when a parallel shift is used the functional form is largely irrelevant, and that a linear model provides a good approximation to the true (unknown) functional form of supply and demand.

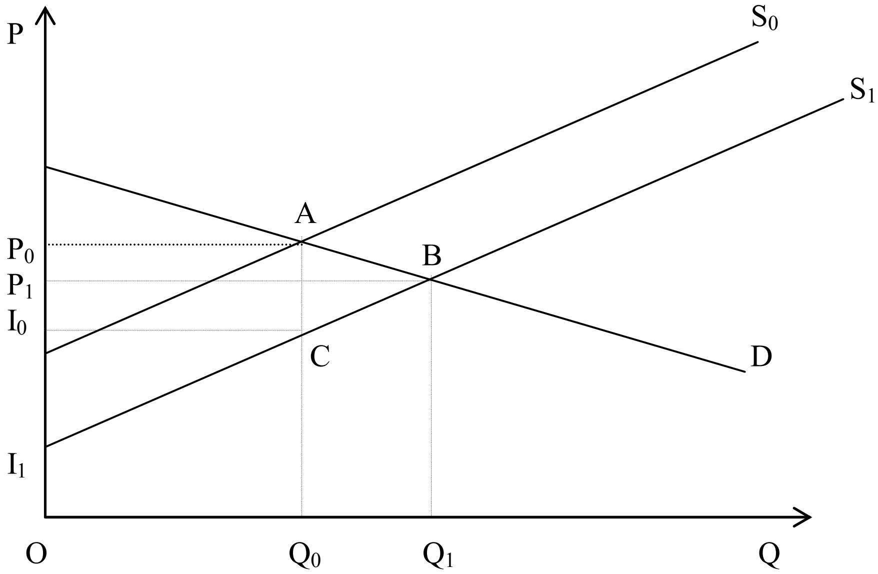


**Figure 3: Estimating changes in producer and consumer surplus**

A hypothetical case is illustrated in Figure 3. The supply of maize before the technical intervention of BNMS technology is denoted by $S_0$. The demand for maize is denoted by D. The supply of maize shifts to $S_1$ following adoption, changing the equilibrium price and quantity before intervention from $P_0$ and $Q_0$ to a new equilibrium price and quantity, $P_1$ and $Q_1$. The change in consumer surplus is the area represented by $P_1P_0AB$ and the change in producer surplus is the area covered by $P_1BCE$. The change in total surplus is the sum of consumer and producer surpluses, which can be shown to be equal to $I_1I_0AB$.

In a closed economy, economic surplus measures can be derived using formulas presented in Alston et al. (1995): (1) economic surplus (ES) = $P_0Q_0K_t(1+0.5Z_t\eta)$; (2) consumer surplus (CS) = $P_0Q_0Z_t(1+0.5Z_t\eta)$; and producer surplus (PS) = $(K_t-Z_t)P_0Q_0(1+0.5Z\eta)$, where $K_t$ is the supply shift representing the product of cost reduction per ton of output as a proportion of product price ($K$) and technology adoption at time $t$ ($A_t$), both of which have been presented and discussed earlier; $P_0$ represents pre-research price (US\$/ton); $Q_0$ is quantity of maize in tons; η is the price elasticity of demand; and $Z_t$ is the relative reduction in price at time $t$, which is calculated as $Z_t = K_t\varepsilon/(\varepsilon+\eta)$, where ε is the price elasticity of supply. Similarly, Alston et al. (1995) show that, in a small open economy, change in economic surplus is equal to change in producer surplus and can be calculated as ES = PS = $P_wQ_0K_t(1+0.5K_t\varepsilon)$, where $P_w$ is the real world price.

*Prices and price elasticities*

In view of the fact that maize is a highly tradable commodity on regional as well as international markets, however, the base model uses the open economy framework, and average international maize prices for 1997–2006 adjusted for shipping and insurance were used in valuing the research benefits. The average real international maize price thus estimated was US$121/ton. There is no reliable estimate of maize supply elasticity for West Africa. Following Alston et al. (1995) in such situations, the price elasticity of maize supply was assumed to be 1. Given that maize is an important staple for most households in West Africa, the (absolute) price elasticity of demand for maize was assumed to be 0.4.

*Research lag*

A research lag of ten years was assumed from the year of initial research investment in 1997 to the beginning of adoption of BNMS technologies in non-project villages in 2007. Although there was adoption of BNMS-manure as well as BNMS-rotation – i.e. in the project villages – in Nigeria well before 2007, it was not significant when measured as a proportion of total maize area in the NGS of West Africa. There was adoption of BNMS technologies following major extension efforts starting in 2006 with, for example, the development and dissemination of extension materials on maize production in rotation with soybean.

*Research and extension costs*

The total costs for research, development and extension of BNMS technologies from 1997 to 2006 were obtained from the BNMS project management at the IITA. The research costs included the annual salary of the BNMS research team; the annual operational expenses required to undertake the technology development (basic research in advanced labs, on-farm trials and demonstrations, etc.), packaging, and diffusion of BNMS technologies; and the annual overhead costs at the IITA. The annual extension costs associated with the large-scale dissemination of BNMS technologies in the NGS of West Africa were estimated at US$2.5 million for the expected 15 years – from 2007 until the adoption of BNMS technologies reaches the ceiling of 40% for BNMS-rotation and 48% for BNMS-manure.

## 3. Results

This section presents and discusses the base model results of the benefit : cost analysis for soil fertility management options in West Africa. The benefits and costs of BNMS research and extension were arrayed on a yearly basis from 1997 to 2030, and a discount rate of 5% was applied to calculate the net present value of benefits from BNMS research and extension efforts as total discounted net benefits of total discounted costs. The internal rate of return was also calculated as the discount rate at which the net present value is zero and can be compared to the opportunity cost of funds. The benefit : cost ratio was also calculated as total discounted benefits divided by total discounted costs. Sensitivity analyses were also conducted to test the sensitivity of the estimated benefits and rates of return to changes in the values of key parameters as well as model assumption. An important assumption underlying the analyses of potential benefits and rates of return is that promotional efforts target only one BNMS technology option.

Tables 4 and 5 present the estimated benefits and costs for BNMS-manure and BNMS-rotation, respectively. With the bulk of the research expenditure made before 2006, the net present values of benefits were negative during the early years of development of the technology. With adoption picking up from 2007, annual benefits quickly offset the research and extension costs and benefits begin to level off as the upper ceiling of adoption is reached after 2020. The results in Table 4 show that Nigeria gains an estimated US$59 million – equivalent to US$2 million per year – from adoption of BNMS-manure, followed by Ghana (US$19 million), Benin (US$14 million) and Togo (US$9 million). The present value of net benefits from BNMS-manure research and extension in West Africa is estimated at US$82 million. The results further demonstrate that BNMS-manure research and extension yields a rate of return of 25% and a benefit : cost ratio of 5 to 1. The estimated rate of return is higher than the prevailing market interest rates and confirms that adoption of BNMS-manure generates a stream of benefits in excess of the research and extension expenditures. The estimated benefit : cost ratio of 5 to 1 indicates, on the other hand, that each dollar invested in BNMS-manure research and extension generates five dollars' worth of additional food.

**Table 4: Present value of benefits and costs for BNMS-manure in West Africa**

| Year | Benefits (US$ million) | | | | | R&E costs (US$ million) | Net benefits (US$ million) |
|---|---|---|---|---|---|---|---|
| | Nigeria | Ghana | Togo | Benin | All | | |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0.36 | -0.36 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0.29 | -0.29 |
| 1999 | 0 | 0 | 0 | 0 | 0 | 0.29 | -0.29 |
| 2000 | 0 | 0 | 0 | 0 | 0 | 0.25 | -0.25 |
| 2001 | 0 | 0 | 0 | 0 | 0 | 0.25 | -0.25 |
| 2002 | 0 | 0 | 0 | 0 | 0 | 0.14 | -0.14 |
| 2003 | 0 | 0 | 0 | 0 | 0 | 0.26 | -0.26 |
| 2004 | 0 | 0 | 0 | 0 | 0 | 0.28 | -0.28 |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0.33 | -0.33 |
| 2006 | 0 | 0 | 0 | 0 | 0 | 0.36 | -0.36 |
| 2007 | 0.20 | 0.06 | 0.03 | 0.05 | 0.34 | 1.46 | -1.12 |
| 2008 | 0.32 | 0.10 | 0.05 | 0.08 | 0.55 | 1.39 | -0.85 |
| 2009 | 0.51 | 0.16 | 0.08 | 0.12 | 0.87 | 1.33 | -0.46 |
| 2010 | 0.79 | 0.25 | 0.12 | 0.19 | 1.36 | 1.26 | 0.09 |
| 2011 | 1.19 | 0.38 | 0.18 | 0.29 | 2.04 | 1.20 | 0.84 |
| 2012 | 1.70 | 0.54 | 0.26 | 0.41 | 2.91 | 1.15 | 1.77 |
| 2013 | 2.27 | 0.73 | 0.35 | 0.55 | 3.90 | 1.09 | 2.81 |
| 2014 | 2.82 | 0.90 | 0.44 | 0.68 | 4.85 | 1.04 | 3.81 |
| 2015 | 3.27 | 1.04 | 0.51 | 0.79 | 5.61 | 0.99 | 4.62 |
| 2016 | 3.55 | 1.14 | 0.55 | 0.86 | 6.10 | 0.94 | 5.16 |
| 2017 | 3.68 | 1.18 | 0.57 | 0.89 | 6.32 | 0.90 | 5.42 |
| 2018 | 3.69 | 1.18 | 0.58 | 0.90 | 6.35 | 0.85 | 5.49 |
| 2019 | 3.63 | 1.16 | 0.57 | 0.88 | 6.24 | 0.81 | 5.42 |
| 2020 | 3.52 | 1.13 | 0.55 | 0.85 | 6.05 | 0.78 | 5.28 |
| 2021 | 3.39 | 1.08 | 0.53 | 0.82 | 5.83 | 0.74 | 5.09 |
| 2022 | 3.25 | 1.04 | 0.51 | 0.79 | 5.59 | 0.70 | 4.88 |
| 2023 | 3.11 | 0.99 | 0.48 | 0.75 | 5.34 | 0 | 5.34 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2024 | 2.97 | 0.95 | 0.46 | 0.72 | 5.10 | 0 | 5.10 |
| 2025 | 2.83 | 0.90 | 0.44 | 0.69 | 4.86 | 0 | 4.86 |
| 2026 | 2.70 | 0.86 | 0.42 | 0.65 | 4.63 | 0 | 4.63 |
| 2027 | 2.57 | 0.82 | 0.40 | 0.62 | 4.41 | 0 | 4.41 |
| 2028 | 2.45 | 0.78 | 0.38 | 0.59 | 4.20 | 0 | 4.20 |
| 2029 | 2.33 | 0.75 | 0.36 | 0.57 | 4.00 | 0 | 4.00 |
| 2030 | 2.22 | 0.71 | 0.35 | 0.54 | 3.81 | 0 | 3.81 |
| Total | 59 | 19 | 9 | 14 | 101 | 19 | 82 |
| Annual | 2.3 | 0.7 | 0.4 | 0.5 | 3.9 | 1 | 2 |
| Rate of return (%) | | | | | | | 25 |
| Benefit : cost ratio | | | | | | | 5 |

*Source:* Authors' computation

As a soil fertility management option, maize–soybean rotation appears to have even greater potential for generating productivity gains and economic benefits in excess of the expenditures. The results in Table 5 show that Nigeria gains an estimated US$274 million – equivalent to US$11 million per year – from adoption of BNMS-rotation, followed by Ghana (US$88 million), Benin (US$67 million) and Togo (US$13 million). The present value of net benefits from BNMS-rotation research and extension in West Africa is estimated at US$452 million. The results further demonstrate that BNMS-rotation research and extension yields a rate of return of 43% and a benefit : cost ratio of 24 to 1. The estimated rate of return is much higher than the prevailing market interest rates and confirms that the adoption of maize–soybean rotation generates a stream of benefits in excess of the research and extension expenditures. The estimated benefit : cost ratio of 24 to 1 indicates that each dollar invested in BNMS-rotation research and extension generates 24 dollars' worth of additional food.

**Table 5: Present value of benefits and costs for BNMS-rotation in West Africa**

| Year | Benefits (US$ million) | | | | | R&E costs (US$ million) | Net benefits (US$ million) |
|---|---|---|---|---|---|---|---|
| | Nigeria | Ghana | Togo | Benin | All | | |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0.36 | -0.36 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0.29 | -0.29 |
| 1999 | 0 | 0 | 0 | 0 | 0 | 0.29 | -0.29 |
| 2000 | 0 | 0 | 0 | 0 | 0 | 0.25 | -0.25 |
| 2001 | 0 | 0 | 0 | 0 | 0 | 0.25 | -0.25 |
| 2002 | 0 | 0 | 0 | 0 | 0 | 0.14 | -0.14 |
| 2003 | 0 | 0 | 0 | 0 | 0 | 0.26 | -0.26 |
| 2004 | 0 | 0 | 0 | 0 | 0 | 0.28 | -0.28 |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0.33 | -0.33 |
| 2006 | 0 | 0 | 0 | 0 | 0 | 0.36 | -0.36 |
| 2007 | 1.12 | 0.36 | 0.17 | 0.27 | 1.93 | 1.46 | 0.47 |
| 2008 | 1.69 | 0.54 | 0.26 | 0.41 | 2.91 | 1.39 | 1.52 |
| 2009 | 2.53 | 0.81 | 0.39 | 0.61 | 4.34 | 1.33 | 3.01 |
| 2010 | 3.70 | 1.18 | 0.58 | 0.90 | 6.35 | 1.26 | 5.09 |
| 2011 | 5.28 | 1.69 | 0.82 | 1.28 | 9.07 | 1.20 | 7.86 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2012 | 7.26 | 2.32 | 1.13 | 1.76 | 12.48 | 1.15 | 11.33 |
| 2013 | 9.55 | 3.05 | 1.49 | 2.32 | 16.40 | 1.09 | 15.31 |
| 2014 | 11.88 | 3.80 | 1.85 | 2.88 | 20.41 | 1.04 | 19.37 |
| 2015 | 13.96 | 4.47 | 2.17 | 3.39 | 23.99 | 0.99 | 23.00 |
| 2016 | 15.54 | 4.97 | 2.42 | 3.77 | 26.71 | 0.94 | 25.76 |
| 2017 | 16.53 | 5.29 | 2.57 | 4.01 | 28.40 | 0.90 | 27.50 |
| 2018 | 16.96 | 5.43 | 2.64 | 4.12 | 29.15 | 0.85 | 28.29 |
| 2019 | 16.97 | 5.43 | 2.64 | 4.12 | 29.16 | 0.81 | 28.34 |
| 2020 | 16.68 | 5.34 | 2.60 | 4.05 | 28.66 | 0.78 | 27.89 |
| 2021 | 16.21 | 5.18 | 2.52 | 3.93 | 27.85 | 0.74 | 27.12 |
| 2022 | 15.64 | 5.00 | 2.43 | 3.79 | 26.86 | 0.70 | 26.16 |
| 2023 | 15.01 | 4.80 | 2.34 | 3.64 | 25.79 | 0 | 25.79 |
| 2024 | 14.37 | 4.59 | 2.24 | 3.48 | 24.68 | 0 | 24.68 |
| 2025 | 13.72 | 4.39 | 2.14 | 3.33 | 23.58 | 0 | 23.58 |
| 2026 | 13.09 | 4.19 | 2.04 | 3.18 | 22.50 | 0 | 22.50 |
| 2027 | 12.49 | 3.99 | 1.94 | 3.03 | 21.45 | 0 | 21.45 |
| 2028 | 11.90 | 3.81 | 1.85 | 2.89 | 20.45 | 0 | 20.45 |
| 2029 | 11.34 | 3.63 | 1.77 | 2.75 | 19.48 | 0 | 19.48 |
| 2030 | 10.80 | 3.45 | 1.68 | 2.62 | 18.56 | 0 | 18.56 |
| Total | 274 | 88 | 43 | 67 | 471 | 19 | 452 |
| Annual | 11 | 3 | 2 | 3 | 18 | 1 | 13 |
| Rate of return (%) | | | | | | | 43 |
| Benefit : cost ratio | | | | | | | 24 |

*Source:* Authors' computation

*Sensitivity of results to changes in key parameters*

A sensitivity analysis was undertaken to evaluate the robustness of the estimated benefits with respect to model assumptions and certain parameter values. Apart from the model assumption (i.e. closed vs open economy), the analysis focused on assessing the effects of (1) halving the expected adoption rates and (2) doubling the extension costs. Indeed, expected adoption and extension costs are the two most important parameters with less certain values. The adoption rates observed in the BNMS project villages serve as a good basis for extrapolation, but these may not apply to the rest of West Africa. While the BNMS research costs are actual investments by the IITA and the Katholieke Universiteit Leuven, the extension costs are not. Research benefits are also sensitive to the price elasticity of supply, but this is mainly the case when the value of the supply shift associated with unit cost reduction is approximated as experimental yield gains (i.e. horizontal supply shift) divided by supply elasticity (Alston et al., 1995). In this study, the supply shift was derived on the basis of unit cost reductions calculated directly from the detailed partial budgets presented in Table 2. The price elasticity of demand, on the other hand, influences the distribution of benefits between producers and consumers and not the total benefits.

**Table 6: Sensitivity of the results to changes in the values of key parameters**

| | Key parameter change | Net present value (US$ million) | Rate of return (%) | B:C ratio |
|---|---|---|---|---|
| BNMS-manure | Baseline | 82 | 25 | 5 |
| | Halving adoption rates | 31 | 17 | 3 |
| | Doubling extension costs | 65 | 20 | 3 |
| | Closed economy | 80 | 25 | 5 |
| BNMS-rotation | Baseline | 452 | 43 | 24 |
| | Halving adoption rates | 206 | 35 | 12 |
| | Doubling extension costs | 435 | 41 | 13 |
| | Closed economy | 422 | 43 | 23 |

The results of the sensitivity analysis are presented in Table 6. For BNMS-manure, halving the expected adoption rates reduces the present value of benefits by more than half, from US$82 million to US$31 million, but only reduces the rate of return from 25% to 17%, indicating that BNMS-manure would still be socially profitable. Doubling the extension costs has much less effect on the estimated benefits and rate of return – here, the benefits are reduced to US$65 million and the rate of return to 20%. The model assumption has little or no effect on estimated benefits and rate of return, with both open and closed economy models yielding the same 25% rate of return. Similarly, for BNMS-rotation, halving the expected adoption rates reduces the present value of benefits by more than half, from US$452 million to US$206 million, but only reduces the rate of return from 43% to 35%, indicating that BNMS-rotation would still be highly profitable. Doubling the extension costs has much less effect on the estimated benefits and rate of return – here, the benefits are only reduced to US$435 million and the rate of return to 41%. As in the case of BNMS-manure, the model assumption has little or no effect on estimated benefits and rate of return, with both open and closed economy models yielding the same 43% rate of return. The estimated benefits are sensitive to expected adoption rates but much less so to changes in costs and model assumptions. Overall, both BNMS-manure and BNMS-rotation are socially profitable even under the more conservative adoption scenarios.

## 4. Summary and conclusion

Building on the successes of the strategic natural resource management research conducted at the IITA since the early 1980s, a collaborative project between IITA and Katholieke Universiteit Leuven was developed and tested. It promoted balanced nutrient management systems (BNMS) technologies as part of a major effort to address plant nutrient depletion in maize-based farming systems in the NGS zone of West Africa. Specifically, the project developed and tested two major soil fertility management options: a combined application of inorganic fertilizer and manure, and a maize–soybean rotation practice. The technology options were developed and tested on-station and on-farm for their agronomic robustness in Nigeria, Ghana, Benin and Togo. The combined application of organic and inorganic fertilizer brings about an estimated saving of about 50% of the cost of nitrogen fertilizer. On the other hand, maize–soybean rotation involving late-maturing soybean varieties contributes residual nitrogen to maize through biological nitrogen fixation. Past empirical work on the economics of soil fertility management options demonstrated the profitability of both BNMS-manure and BNMS-rotation compared with the typical farmer practice of continuous maize cultivation. However, no study has been undertaken to assess the potential economic impacts of BNMS technologies to guide further investments in research and extension in West Africa.

Using the economic surplus model, the present study assessed the potential economic impacts of soil fertility management research and extension in West Africa. The economic surplus analysis revealed that BNMS-manure generates net benefits in the range of US$31 million under a conservative scenario with 24% maximum adoption to US$82 million under the base scenario with 48% maximum adoption. The corresponding internal rate of return to BNMS-manure research and extension ranges from 17% under the alternative scenario to 25% under the base scenario. Similarly, the analysis showed that the net economic benefits from BNMS-rotation range from US$206 million under a conservative scenario with 20% maximum adoption to US$452 million under the base scenario with 40% maximum adoption. The corresponding internal rate of return to BNMS-rotation research and extension ranges from 35% under the alternative scenario to 43% under the base scenario. The robustness of the rate of return results, under any of the alternative scenarios, indicated the social profitability of both soil fertility management options. Consistent with earlier economic analyses showing the greater profitability and farmer acceptability of BNMS-rotation involving maize cultivation in rotation with soybean, our results thus demonstrated that maize–soybean rotation generates greater productivity gains and economic benefits than BNMS-manure. Apart from the observed lower yield gains, the scope for achieving large-scale adoption of BNMS-manure may be limited since there are no markets for manure. Overall, while the potential economic gains are considerable, realization of these gains depends on the efficiency and effectiveness of extension and input supply systems. Concerted extension efforts are needed to stimulate demand for these soil fertility management options, using extensive participatory demonstrations, and because the BNMS options are knowledge-intensive, considerable technical advice is also needed to explain how to apply them.

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