Precision Farming as a Tool in Reducing Environmental Damages in Developing Countries: A Case Study of Cotton Production in Benin

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Abstract

Government subsidies designed to encourage cotton production in Benin have resulted in unsustainable agricultural production practices. Properly introduced, precision farming technology can help farmers improve their management practices and stop the damages being done to the environment. An economic analysis of the impacts of subvention policies is performed. Results show that an increase in input cost has a marginal impact on farmers' production strategy.

Introduction

The issue of land degradation is probably one of the most important farmers in most developing countries have to face. Changes in production practices caused by a continuous pressure on available land and government incentives have lead to an increased soil nutrient depletion. It was estimated that about 86% of African countries show annual nutrient deficits greater than 30 kilograms of NPK per hectare of cropped land per year (Henoa and Baanante). This nutrient balance results in a widening gap between the potential and realized farm yields. In Sub-Saharan African (SSA) countries, for example, annual use of NPK per hectare averages only 10 kilogram per hectare. This very low average mainly results from the lack of fertilizer use in the production of most food crops in those countries. Fertilizer is mainly made available for cash crop production because of its higher profitability. However, because of their high cost and limited availability (government controlled), fertilizers are usually not applied in sufficient quantity to make up for the soil nutrient loss. As a result, in the absence of adequate

increases in agricultural productivity, farmers reduce needed fallows and expand into new areas often causing environmental damages. There is today a great need of implementation of new management practices and technological support that will help farmer reverse the trend toward a continuous deterioration of their production environment.

Because of its ability to spatially manage the land and make an optimal use of scarce agricultural inputs (seed, fertilizer and pesticide) available to farmers in developing countries, PA should prove to be a relevant technology to be adopted by those farmers. Though the information technology that lies in the heart of PA is clearly unattainable and inappropriate to those farmers, the principle of using spatial information has much to offer. The technologies to be adopted and the methods of adoption should however be specific to meet each country's production constraints and suitable technology. In Asia for example, PA production concepts have been experimented and adopted in rice and oil palm production. Dobermann et al. conducted a major field research in six countries (China, India, Indonesia, Philippines, Thailand and Viet Nam) on the application of site-specific nutrient (SSNM) management for intensive rice cropping. They found that the application of SSNM resulted on an average of 11% increased in yield while reducing fertilizer application by 4%. SSNM on averaged increased profitability by 12% and required little extra credit for financing its adoption. However, for some producers the adopting PA resulted in net losses mainly because of the minimum crop care requirement. In Malaysia, a PA technology (remote sensing) is applied in the production of oil palm (Zainal Abidin Hasan). In Latin America, the application of PA techniques is slowly growing. In Argentina, adoption of PA is growing

slowly. Yield monitors have been installed on 1% to 2% of all combines compared to about 4% in North America (Loweenberg-DeBoer). Variable rate application (VRA) is however unlikely to grow at this stage because of the high cost of soil sampling. It is expected that the development of PA will come through more extensive use of lower cost technologies as yield maps or aerial photographs. With the exception of South Africa, the adoption of PA is unknown in SSA. Given the specific problems that SSA farmers are facing - soil nutrient depletion, soil erosion, insufficient use of fertilizer- due to insufficient use of fertilizer and changes in production practices, PA technology can become a valuable production tool if adapted to farmers' current production practices and level of education. Like oil palm in Malaysia or rice in Thailand, cotton production can be an excellent case study for the adoption of PA in SSA.

Background

   Over the past 20 years, cotton production has been one of the rare success stories for Sub-Saharan African (SSA) countries. Production grew three times faster than anywhere else in the world (Goreux and Macrae, 2002). For many SSA countries, such a growth was only made possible through government intervention. The good performance achieved by countries like Benin, Mali or Zimbabwe "reflects effective vertical coordination, strong research and extension systems, and significant subsidies that have helped to maintain production levels during world market prices downturns" (Boughton et al., 2003). For those countries, cotton has become "the main cash crop and the largest source of export receipts and government revenues" (Ousmane et al. 2002)

In Benin government subsidies along with a good organization of cotton sector not only makes cotton production more profitable than other crops but also warranty to farmers the immediate sale of their entire production at a previously fixed price. In regions most suitable for cotton production, farmers have progressively abandoned crop rotation and fallow for an almost continuous cotton production. This practice, coupled with inappropriate fertilization management and increasing demographic pressure, has led to significant deterioration in soil productivity and land degradation across these regions. Farmers increasingly clear frontier land in the nearby the national reserve park causing major environmental damage for the region and the country as a whole.

Though the seriousness of the situation for the long term sustainability of cotton production is recognized by both local authorities and farmers, a viable solution has not yet been found. This paper offers solutions that could be implemented not only by Benin cotton producers but also by other SSA producers facing with similar problems. Using PF technology to deal with specific environmental problems faced by SSA countries has not yet been addressed in the literature. In this model, environmentally sound practices are achieved when farmers adopt PF and a soil specific crop rotation strategy that enables them to crop their existing land in a profitable and sustainable way without having to clear frontier land. The targeted region is Banikoara County in Northern Benin that is by far the largest cotton producing county in the country.

Study Region background

Banikoara is the largest cotton production county in Benin. It covers an area of 4,383 km² of which 49% is covered by the "W" National reserve in the north. The population is

estimated to be 132,000 inhabitants. Cotton has been part of the production system for many decades. According to the national soil survey done in the early 1960s, the county possess some of the best soil suitable for cotton production. It has a favorable climate for cotton production. Northern Benin processes a semi-arid climate with a single raining season. Rainfall reaches approximately 900 mm annually, roughly between May and October. The rest of the year is dry and allows farmers to safely cropping the cotton (cropping season last for up to four months) without the risk to have the fiber get wet. . During the ten fifteen years, cotton acreage has increased by more than 128% (Ministère de l'Agriculture, de l'Elevage et de la Pèche. Sous prefecture de Banikoara). This sustained increased in production during the last ten years is motivated by a governmental policy that supported cotton price and guaranty to farmers the purchase of all their production.

Cropping practice background

In Banikoara cropping activities are done both manually and with the help of animal traction. Compared to the rest of the country were most cropping activities are performed manually with rather simple tools (hoes, axes, digging bar and knives), most Banikoara farmers use animal traction for most field work. New and fallow land are usually cleared and burn to reduce the effect of shading on crops, fertilize the soil with litter and ashes, reduce sprouting of herbs and ease weeding (Michael Brüntrup). Though plane plowing is officially recommended, farmers usually use ridging because it is easier and less time consuming. They usually use herbicide to control weed. Seeding and cropping are usually

performed manually. If the cropping practices have not much evolved over the last four decades, cropping systems have changed.

Traditionally, cropping system was based on a 5 years rotation of sorghum at the beginning of the rotation (because farmers traditionally do not use fertilizer to produce sorghum), two years of cotton followed by corn (to benefit from the after effect of cotton) and peanut or any other leguminous. Fallow then usually lasted from 4 to 10 years depending on the original quality of the land (Sylvain Kpenavoun). The longer a field is laid fallow, the more fertile the soil but the more burdensome it is to clear, whereas for shorter fallow periods less effort is necessary to gain new land but the fertility will be lower and the cropping period eventually shorter. But today, farmers tend to continuously produce cotton for 4 to 5 years until complete impoverishment of the soil. A typical rotation would now be sorghum-cotton-cotton- cotton-corn-peanut. Then the land would be left for 2 to 3 fallow in the best scenario. Changes in traditional practices were mainly motivated by increasing scarcity of land due to population pressure and the increased in land area allocated to cotton. Cotton production today represents more than 58% of total cropping area on average followed by corn 27%, sorghum, 6% and peanut, 3% representing the four major crops (Sylvain, Kpenavoun). Given the significant changes the cropping system and its impact on the sustainability of agricultural production Banikoara, a mathematical programming model was developed to analyze the production behavior of a profit maximizing cotton producer.

Model Specifications

In this study a mathematical programming model was used to model the production environment of a hypothetical Banikoara farmer producing cotton, corn and grain sorghum. He can choose to either use precision agriculture technology (variable rate application of fertilizer), or conventional technology (uniform rate application of fertilizer). It is hypothesized that the ability to variably apply fertilizer and gives the producer much more control over his production environment and may represent a powerful mean to manage production risk. It is also assumed that the farmer's objective is to maximize expected utility.

The model is a model of crop rotation under perfect knowledge of price, yield and cost of production. The model select the optimum crop rotations and the proportion of land resource allocated to each crop on a given soil type; it is assumed three different types of soil. An equilibrium known life type of model is most used to determine the optimal crop rotation that will maximize the farmer's net return above variable cost. In an equilibrium model, the farmer is assumed to be in steady-state equilibrium. This means that once the optimum crop rotation has been determined, the same decisions are repeated in each and every future period. However, this type of model assumes that the resources available to the farmer (land, labor, capital, etc) are available in the same amount on a continuous basis and that each activity uses the same amount of resource. Though this assumption would not always hold for labor and capital constraint, it is a reasonable to assume that farmers crop the same land year after year. This approach is preferred to the disequilibrium known approach given that the farmer's needs not to know the optimum crop rotation path over a given period of time but rather an optimum given rotation. The objective here is to depict an equilibrium one year model where the farmer adopts the

same rotation practice regardless of a given weather of economic condition. In this model, the rotation activities are endogenously chosen and form by the model. The best rotation possibilities are considered and automatically chosen by the model.

Given that risk is a key component of farmer's production choices, the current study relies upon the expected utility framework to analyze the production risks included in the objective function. The technique used here is known as expected value variance (E-V) analysis and was first developed by Markowitz for its application in mathematical programming. It allows an analysis of the farmer's profit maximizing production strategies under different risk aversion level. Though highly criticized in the past, it has been shown to be consistent with the expected utility theory (Freund, Meyer, Markowitz). Risk is measured in term of variance of crop (or enterprise) net income. If three enterprises fall on the same mean-variance (E-V) frontier, then they are all efficient in an E-V sense, and all three producers could be rational in the sense that they maximize utility. It is accepted that the expected income is a decreasing function of the risk aversion level. That is, the more risk averse the farmer is, the lower his/her expected income will be

The general specification of the model is as followed:

Objective functions:

$$\text{Max } \overline{Y} - \Phi s_Y^2$$

In this formulation, the farmer maximizes the expected average (across years) return, $\overline{Y}$ above variable costs. Φ is the Pratt risk-aversion coefficient and s_Y^2 is the variance of the expected annual return above variable cost.

a. Sales balance

$$-\sum_S \sum_P \sum_C \sum_{C'} \sum_F \text{YLD1}_{N, C, C', S, F} * \text{HA}_{S, P, C, C', F}$$

$$-\sum_S \sum_P \sum_C \sum_{C'} \sum_F \text{YLD2}_{N, C', C, S, F} * \text{HA}_{S, P, C', C, F}$$

$$+ \text{SALES}_Y = 0 \qquad \forall_{C, C', N}$$

In this model, we have a two years crop rotation. $\text{YLD1}_{N, C, C', S}$ is the first year

(beginning of the rotation) expected yield during year N for enterprises (crop) C and C',

on soil type S (in tone per ha) and $\text{YLD2}_{N, C, C', S}$ is the expected yield of the second year

crop (C) following first year crop C during year N for enterprises C and C', on soil type

S. $\text{HA}_{S, P, C, C', F}$ is the number of ha produced for enterprise C and C' on soil S under

production strategy P (precision agriculture of conventional production) at fertilizer level

F. SALES_N is the total farm sale in year N (in tone).

b. Input balance

$$\sum_S \sum_P \sum_C \sum_{C'} \sum_F \text{IREQ}_{C, F, T} \, \text{HA}_{S, P, C, C', F} - \text{IPURCH}_{N, T} = 0 \qquad \forall_{T, N}$$

This input purchase balance equation determines the total quantity of input used during

the season by year (N) and input type (T). $\text{IPURCH}_{N, T}$ is the total quantity of input T

used during the cropping season (N) and $\text{IREQ}_{C, F, T}$ is the quantity of input required per

crop, fertilizer level and input type.

c. Profit balance

$$\sum_P \sum_E P_C * \text{SALES}_{CN} - \sum_I \text{IP}_T \, \text{IPURCH}_T + Y_N = 0 \qquad \forall_N$$

In the sales balance equation, it is assumed that the entire crop produced is sold by the

end of the year. P_C is the crop price, SALES_{CN} is the quantity sold, IP_T is the input cost,

$IPURCH_T$ is the quantity of input purchased and Y_N is the expected net returns above variable cost (across years).

d. Land constraints

$$BASEHA_{S, N=1} = 2$$

$$\sum_{C'}\sum_{C}\sum_{F}\sum_{P} HA_{N=1, P, S, C, C', F} = BASEHA_{Y, S} \qquad \forall_{N, S, C}$$

$$\sum_{C'}\sum_{C}\sum_{F}\sum_{P} HA_{N, P, S, C, C', F} = BASEHA_{Y, S} \qquad \forall_{N >1}$$

The first equation fixes the amount of land that was planted the first year at 2 ha for each soil. The second set up the initial acre in year one as the available land for that year. Finally the last equation, BASEHA is the total number of acres available to the farmer (6 ha)

$$BASEHA_{N, S'} * HA_{FSP} - BASEHA_{S} * HA_{FS'P} = 0 \; \forall \; P, F, S \; ? \; S'$$

$$BASEHA_{N, S'} * \sum_{E} HA_{FSP} - INHA_{S} * \sum_{E} HA_{FS'P} = 0 \quad \forall \; P, F, S \; ? \; S'$$

6a or 6b) ratio constraint to control for non-variable rate management strategy under either conventional (a) or PA variable application (b)

Summary of indices:

C represents the different enterprises or crops (corn, wheat and soybean)

P is the input management strategy (single or variable rate application)

S represents the three soil types (bani1, bani2 or bani3)

F is the fertilizer application level (low or medium)

T type of input used (fertilizer or pesticide)

N number of years

Data and Production Methods

The source of the data used in this model will be discussed in the following section. The data required in the development of the model include: (1) yield, (2) soil types and land available for production, (3) production budgets, 4) Crop and input prices Most of the data used was collected during a field trip in Benin in August and September 2003.

(1) Crop yield data.

Crops yields were obtain using WinEpic, an interface to EPIC (Erosion-Productivity Impact Calculator). WinEpic adds to EPIC a window interface, economic data and production practice environment familiar to economists. Simulation models are capable of simulating crop variables and management practices as plant population, planting and harvesting dates, maturity groups, irrigation, drainage systems, tillage, irrigation methods, etc. Compared to other crop growth models, EPIC has the capability to simulate yield data when fertilizer levels are varied. The model was then calibrated to fit Banikoara production conditions: historical weather data, soil characteristics, fertilizer and chemical levels as well as sowing dates. The weather and soil data were obtained from INRAB (Benin National Institute for Agricultural Research). Typical recommendations for planting dates, types, quantity, time and frequency of chemical and fertilizer application were obtained from a survey of local farmers.

The model generates expected yields for corn, cotton and sorghum for varying fertilizer levels (nitrogen, phosphorus and potash), and traditional planting dates. Two fertilizer levels were used to generate three series of yield data on each type of soil. The

medium level corresponds to the exact recommendations made to farmers by county agents. Yield data using low level of fertilizer application was also generated because of common practices of application of lower than recommended levels of fertilizer. The fertilizers varied were urea, nitrogen, phosphorous and potassium for corn, cotton and sorghum. Crop yield were validated based on Northern Benin field trial results as well as individual farmers yield data were used to validate the model (CRA-CF). The Model does a reasonable work simulating corn, cotton and sorghum yields. Yield data are in the range of field trial yield obtain in Banikoara. However, these yields are much higher than county average yields. The county average yield includes all types of soils, production practices and most important varieties. For corn production for example, in spite of the wide availability of high yielding corn seed for example, farmers continue to devote a relatively large land areas to the production of traditional low yielding crops for domestic consumption. As a result, for a six years county average yield for corn of 1640 kg/ha, EPIC simulated 2831 kg/ha. Historical field trial data were however not available to compare the variance with the one obtain with EPIC. Yield simulations also show lower crop yields in the rotation compared to single runs. Second year crop yield in the crop rotation is lower than the yields without the rotation.

(2) Soil types and land available for production.

Three soil types were selected for the simulations. The first soil (Bani1) is silt-loamy soil, the second (Bani2) a clay-loamy soil and the third soil a silt soil (Bani3). For historical reasons most farming units have two to six different fields often if different geographic area. It is not uncommon for two fields to be distant by dozens of kilometers.

(3) Production budgets.

Production budgets were created for each crop to obtain annual input and total variable production cost for each crop. Data were obtained through farmers' survey and personal communication from county agents. Some data were Adegbidi dissertation theses.

(4) Crop and input prices

Crop and input prices were collected from the Ministry of agriculture.

Results and Analysis

At this stage of the research, the model development is in its early stage and results herein presented are provisional and further analysis and model development need to be conducted. In the current model an optimal two years crop rotation solution is chosen per soil, fertilizer level and cropping strategy. Two simulations are performed to analyze the impact of a 15% increase in fertilizer cost on production practices. According to the investigations done during the field trip, the interest rate on credit made to farmers ranges from 12 to 25%. So, given the interest rate commonly gramted to farmers 15% would be an approximate interest rate that they would have to pay in the instance where cease to deliver inputs to farmers credit free.

The objective function is the net return above variable costs for the two years crop rotation. In the summary statistics (table 1), four level of risk aversion were chosen. Level 50 indicates that the producer is risk neutral and level 90 that the producer is risk averse. The net return for an average producer in Banikoara farming 6ha of corn, cotton

or sorghum is $ 12,569 over a two years period. This figure would be at the high end of an expected net return for this type of farmer, but within a reasonable range. In the case of a 15% interest rate added to the input cost, net return above variable rate for a risk neutral farmer would drop to $12,372. In both scenario, the risk averse farmer's net return is about half of the one of the risk neutral producer. It could be expected significant changes in production practices.

One of the major information provided by this model is the absence of sorghum production in the optimum cropping system. This result can be in part explained by the model data. In order to depict producer's production practices as accurately as possible, no fertilizer was apply to sorghum production which resulted in relatively low yields. In reality, sorghum is mainly produced for domestic consumption and farmers are usually reluctant to plant high yielding grain varieties. They also do not usually apply fertilizer on sorghum and prefer planting sorghum at the beginning of the rotation. It is also important to notice that fewer research and appropriate fertilizer dose recommendation are available in Benin for this crop. In this model, even the most risk averse producer does not include sorghum in his/her cropping system. This result may justify the lower and lower acreage allocated to sorghum production as more fertilizer becomes available for the cotton and corn production. Corn and cotton are therefore the two crops planted.

The optimum crop rotations presented in Table 2 and Table 3 provide some interesting results. It can first be noticed that all the land available is utilized at all risk aversion level. At the current fertilizer price, the optimum crop rotation for the risk neutral farmer is the corn-cotton (corn the first year and cotton the second year). Only one ha is allocated to consecutive corn rotation. The risk averse producer tends to

diversity his/her production practice in order to reduce risk. There is slight reduction in the fertilizer usage as more land is allocated to the production of low fertilizer corn-cotton rotation. Risk averse farmers also produce continuous cotton while risk neutral ones produce cotton only in the second year of the rotation. The acreage allocated to cotton also slightly increases as the risk aversion level increases as well.

With the increase in input cost, farmers tend to increase the acreage of the crop using the least input quantity (corn in this case). They also favor production strategies using lower level of fertilizer application.

Conclusion

At this stage of the research, the choice on only two crops and two years rotation do not leave sufficient room for a real economic analysis. An important trend that can however be rise a certain level of interest is the fact that risk averse farmers tend to allocate more area of their land to the production of continuous cotton. Given that the model does not include price risk analysis and is limited to production risk, it could point in the direction of other factors other than the guaranty of a stable price that motivates farmers to produce continuous cotton.

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Table 1: Summary Statistics at current input cost

Risk aversion Level	Current input price				
	50	60	70	80	90
OBJ	11157	8309	7482	6871	6395
MEAN	12569	9335	8725	8089	7467
MAXPROF	35715	13095	10348	8979	7953
MINPROF	0	0	0	872	2072
VAR	4.72E+10	5.40E+09	3.16E+09	1.93E+09	1.11E+09
STD	8871.53465	2999.66167	2293.63	1791.63	1361.77833
CV	79.51	32.13	26.29	22	18

Obj = Objective function
Mean = mean profit
Maxprof = maximum profit
Minprof = minimum profit
Var = variance of profit
Std = standard deviation of profit
CV = coefficient of variation of profit

Table 2: Summary statistics when 15% interest rate is applied to input price

Risk aversion Level	15% increased in input price				
	50	60	70	80	90
OBJ	11088	8129	7234	6706	6290
MEAN	12372	9293	8533	7729	7263
MAXPROF	35091	12929	10105	8597	7733
MINPROF	0	0	0	1685	2522
VAR	44439666667	5936666667	3199533333	1567151667	979380000
STD	8606	3146	2309	1616	1278
CV	77	33	27	21	17

Obj = Objective function
Mean = mean profit
Maxprof = maximum profit
Minprof = minimum profit
Var = variance of profit
Std = standard deviation of profit
CV = coefficient of variation of profit

Table 3: Management practices at current input cost

Rotation	Soil	fert. level	CS	15% increased in input price				
				50	60	70	80	90
				land area	land area	land area	land area	land area
corn-cotton	bani1	med	pa	2	2	1.16	0.51	0.16
corn-cotton	bani1	low	pa			0.84		
cotton-cotton	bani1	med	pa					
corn-corn	bani1	med	pa					
corn-corn	bani1	low	pa				1.49	1.84
corn-cotton	bani2	med	pa	0.94				
corn-cotton	bani2	low	pa		0.42			
corn-corn	bani2	low	pa	1.06	1.06	0.64	1.17	1.42
cotton-cotton	bani2	med	pa		0.52	1.36	0.83	0.58
corn-cotton	bani3	med	pa	2				
cotton-cotton	bani3	low	pa		1.4	1.4	1.08	0.9
cotton-cotton	bani3	med	pa		0.6	0.6	0.92	1.1

CS = Cropping Strategy

fert. Level = fertilizer application level

Table 4: Management practices when 15% interest rate is applied to input price

				Current input price				
				50	60	70	80	90
Rotation	Soil	fert. level	CS	land area	land area	land area	land area	land area
corn-cotton	bani1	med	pa	2	0.17			
corn-cotton	bani1	low	pa		1.83	0.78	0.27	
cotton-cotton	bani1	med	pa			0.21		
corn-corn	bani1	med	pa			1.01		2
corn-corn	bani1	low	pa				1.38	
corn-cotton	bani2	med	pa		0.05			
corn-cotton	bani2	low	pa	1.03				
corn-corn	bani2	low	pa	0.9	1	0.46	0.77	1.12
cotton-cotton	bani2	med	pa		0.95	1.54	1.23	0.88
corn-cotton	bani3	med	pa	2				
cotton-cotton	bani3	low	pa		1.44	1.45	1.23	1
cotton-cotton	bani3	med	pa		0.56	0.55	0.77	1

CS = Cropping Strategy
fert. Level = fertilizer application level