Field Specific Nutrient Management Profitability and Production Risk Analysis: The Case of Cotton Production in Benin

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Abstract

Cotton production is a key export crop factor for the Benin economy. Over the last two decades, the government policies designed to encourage cotton production have resulted in unsustainable agricultural production practices. Properly introduced, field specific nutrition management (FSNM) production techniques could help change current rotation practices that contribute to soil degradation. This paper proposes a method for FSNM adoption for cotton production in Benin. Banikoara, the largest cotton producing county in Northern Benin was chosen for the study. EPIC, a crop growth simulation model was used to estimate crop yield with two levels of fertilizer application. Two mathematical programming models were developed to reproduce the production conditions of a typical cotton farmer using FSNM or conventional production practices. Results show that FSNM is less profitable for the risk neutral farmer but more profitable for the risk averse one when compared to conventional production practices.

Keywords: Precision agriculture, risk, profit, Benin, cotton, technology adoption

1.Introduction

Over the past thirty years, a deliberate effort was made to make cotton production a driving force for economic growth in Benin. In the late nineteen eighties, the government made increased cotton production a key element of its economic development strategy. Considerable efforts were made to re-structure the cotton production sector and encourage production. In 1982, the *Société Nationale de Promotion Agricole (*SONAPA), a state own company was given the responsibility of the cotton sector. Sonapra took over the integrated sector and became the sole cotton input distributor (seed, fertilizer, and pesticide), crop buyer, ginner, and marketer. Inputs were sold to all producers on credit at a unique price, and the repayment deducted from the seed cotton payment at harvest time. The company also had a network of extension specialists that provided free technical assistance and training to farmers. It also guaranteed a minimum and relatively stable seed cotton price. Consequently, cotton producers were shielded from the volatile cotton world prices. As a result, production increased nine-fold from 16,523 tons in 1980 to 425,000 tons in 2004, an average 14% growth rate over a 25 years period. Today, cotton production remains the key driver of the Beninese economy. It covers 37% of the total cropped land and is cultivated in five of the six provinces in the country (World Bank, 2012). The good performance achieved by the cotton sector was only made possible through government intervention that translated into an effective vertical coordination, strong research and extension systems, but also large subsidies that have helped maintain production levels during world market prices downturns (Boughton et al., 2003). For Benin, cotton has become the main cash crop and the largest source of export receipts and government revenues (Ousmane et al. 2003). It represents 90% of the agricultural export, 70% of the country's total exports, and 25% of government income (World Bank, 2002). Unfortunately, the tremendous increase in production also had adverse consequences both on the economy and the environment.

Economically, the vertical integration of the cotton production system under the control of a single company led to chronic mismanagement that forced the Benin government (under international pressure) to liberalize the entire cotton sector from cotton input distribution to cotton fiber export. Under the structural adjustment program signed between the Benin government and the World Bank in 2004, the “institutional” functions assumed by the state owned company had to be replaced by a new and independent structure. The institutional transition process aimed at transferring the key activities controlled by the parastatal (input distribution, ginning, and marketing) to the private sector. The gradual transition from publicly controlled activities to privately controlled ones has faced however, a number of challenges with consequences that are yet to be determined. With regard to the environment, the rapid increase in production has not only disrupted the traditional production cycle in some regions of the country, but also has unveiled long-term environmental and possibly ecological adverse consequences. There is a real need to find a production system that will at least slow the devastating impact that the new changes in the production cycle have had on the environment in the region.

This paper is a contribution not only to the PA agriculture literature but also to the economic development literature. It proposes detailed and innovative techniques for the adoption of PA that are specific to the production environments of a developing country such as Benin. The introduction of technology adoption as a possible mean to mitigate both production and policy risk is an original approach to the major question of poverty reduction.

The objectives of this paper are to propose a framework for precision agriculture (PA) adoption in Benin and evaluate its profitability and its impact on production decisions, more specifically on crop rotation. To meet these objectives, a steady state crop rotation model was developed under a standard expected value variance (E-V) framework using mathematical programming methods. In the remainder of this paper, a framework for Field Specific Nutrition Management (FSNM) adoption in Benin will first be presented. The mathematical programming model developed for the study will be presented followed by a description of the data and an analysis of the results.

2. Concept of field specific nutrient management for Benin production practices

The concept of FSNM refers to the usage of soil sampling to make management recommendations. A single soil sample is taken from a given field that would be identified by the farmer as an independent entity. In Northern Benin (the region of reference for the paper), farmers traditionally have multiple fields typically distant from each other by a few miles and managed individually. If a single field is greater than half a hectare, the farmer would be required to divide it in sub-field, each, smaller than half a hectare. As within soil variability increases with field size, fields larger than a half hectare are likely to be less heterogeneous particular for manual input application. Consequently, it is suggested that the adoption of FSNM should be limited to relatively smallholder farmers. Those farmers usually have an intimate knowledge of their fields and their topography. The FSNM would then be a simple fertilizer application based on field specific soil sampling. This relatively simple concept does not require the use of any computerized technology, but a nutrient application based on fertilizer recommendation tables made available by the national agronomic research center in Benin. The FSNM approach can also rely on the integrated farm management system developed by Benin researchers, and experimented with successfully on a small scale. The system includes the development of area maps representative of farmers’ fields where they can identify roads and trees in and around their fields. They then need to get familiar with the map that serves as a basis for an integrated farm management plan. This work is somewhat similar to what is being done in Columbia and in the Philippines and described by Cook et al. (2003). There, participatory three-dimensional (3-D) mapping is developed using a terrain model as the basic information source, generated by the local community itself. These 3-D maps are, however, expensive to develop and are not likely to be used in Benin in the foreseeing future. The necessity of keeping a very simple field specific fertilizer application system was motivated, among other things, by the number of farmers that would need individual assistance from county agents if they had to use more complex management systems. The FSNM approach will require just a little more assistance than farmers are already receiving from extension agents and will largely rely on the existing agricultural research centers’ expertise to deliver fertilizer application recommendations. Nationally, there may be a need to create one or two additional soil sampling laboratories. As a result, the adoption of FSNM should be easily adaptable for Benin cotton farmers and it is an advantage. There will however be some constraints. The main advantage of the FSNM approach is that farmers would need little or no assistance in implementing it once the soil sampling results and fertilizer application for their respective fields were made available. On the other hand, one of the disadvantages would be the absence of a map that would facilitate record keeping over time.

Another shortfall of this proposal would be its high cost. Soil testing fees in Benin represent about 22% of all of the variable cost and 58% of the fertilizer cost for cotton production if the investment is depreciated in one year. The FSNM cost becomes more reasonable if it is assumed that soil tests are done every four years, as it is a common practice in the United States for example. If depreciated over four years and assuming a continuous cotton rotation, FSNM only represents an estimated 12% of total fertilizer cost. The remaining question is one of capital availability given that in Benin all the fertilizer and pesticide used by cotton farmers is provided to them for credit, reimbursable when the crop is sold, and farmers usually do not have capital available for such investments. The cost of a soil sample can be paid for at the end of the cropping season along with the fertilizer cost if the government makes this type of credit available to farmers. The investment in soil testing will be made only for problem areas previously identified by farmers themselves or with the aid of historical yield data. In that case, if the investment in soil tests is made in areas where the farmer is losing money, it should be immediately recovered. The capital requirement will also be lower given that not all of the fields will need to be sampled. The definition of this framework implies, as it is still the case today, some level of extension assistance is available to cotton producers. The nature of the equipment requirement for PA adoption could significantly slow down its adoption in areas and villages with no access to electricity. The availability to solar energy in SSA has however increased over the past two decades (van der Plas 1994);(Rabah 2005). For the purpose of this research, adoption of FSNM was chosen for the case study because of its accessibility to most cotton producers in Banikoara,is the largest cotton production county in Benin.

2.1. Cropping practices

Traditionally the cropping system in Banikoara was based on a five year 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 fertilizer applied on cotton) and peanut or other leguminous crop. The rotation usually varies from 4 to 10 years, depending on the original quality of the land (Kpenavoun, 2010). The longer a field is laid fallow, the more fertile the soil becomes but the more burdensome it is to clear, whereas for shorter fallow periods less effort is required to prepare the land but the fertility will be lower and the cropping period eventually shorter. Today, farmers tend to continuously produce cotton for four to five years until complete impoverishment of the soil occurs. A typical rotation would now be sorghum-cotton-cotton-cotton-corn-peanut. Then the land would be left for two to three fallow years in the best scenario. Changes in traditional practices were mainly motivated by increasing scarcity of land due to population pressure and the increase 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 (Kpenavoun, 2010). One of the objectives of this research is to investigate whether or not adoption of FSNM would impact the optimum crop mix and crop rotation sequence. A potential shift away from continuous crop rotation with the adoption of FSNM would imply a more sustainable farm management practice. The mathematical programming model developed is now discussed.

3. Model and data

3.1 Model Specifications

In this study, a mathematical programming model was developed to model the production environment of a hypothetical Banikoara farmer producing cotton, corn and grain sorghum. S/he can choose either FSNM technology, or conventional technology (uniform rate application of fertilizer). It is also assumed that the farmer's objective is to maximize the expected net return. The model is a model of crop rotation under perfect knowledge of price, yield distribution and cost of production. The model selects the optimum crop rotations and the proportion of land resources allocated to each crop on a given soil type. It assumes that once the optimum crop rotation has been determined, the same decisions are repeated in each future period. The model also 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 resources. Though this assumption would not always hold for labor and capital constraint, it is reasonable to assume that farmers crop the same land year after year. Three different soil types were used to model the FSNM production method. In this model, the rotation activities are endogenously chosen by the model. Given that risk is a key component of a 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 levels. The E.V modeling technique it has been shown to be consistent with the expected utility theory (Freund 1956, Meyer 1987, Markowitz 1959). Risk is measured in term of variance of crop (or enterprise) net income. 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:

$$\text{Max } \bar{Y} - \Phi\sigma_Y^2$$

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

a. Sales balance

$$-\sum_S\sum_P\sum_C\sum_{C'}\sum_F YLD_{N, C, C', S, F} * HA_{S, P, C, C', F} + SALES_N \leq 0 \qquad \forall_N$$

In this model, we have a two year crop rotation. $YLD_{N, C, C', S,}$is the expected yield during year N for enterprises C and C' (C represents the first crop in the first year of the rotation and C' second crop in the second year of the rotation), on soil type S. $HA_{S, P, C, C', F}$ is the number of hectares produced for cropsC and C' on soil S under production strategy P (FSNM or conventional production) at fertilizer level F. $SALES_N$ is the total farm sale in year N (in tone).

b. Input balance

$$\sum_S\sum_P\sum_C\sum_{C'}\sum_F IREQ_{C, C', F, T}\ HA_{S, P, C, C', F} - IPURCH_{N, T} = 0 \qquad \forall_{T, N}$$

This input purchase balance equation determines the total quantity of input used during the season by year (N) and input type (T). $IPURCH_{N, T}$ is the total quantity of input T used during the cropping season (N) and $IREQ_{C, C', F, T}$ is the quantity of input required per crop C, fertilizer level F and input type T.

c. Profit balance

$$\sum_P\sum_C\sum_{C'} P_C * SALES_{C, C', N} - \sum_P\sum_C\sum_{C'} VC_{P, C, C'} - \sum_T IP_T * IPURCH_T - Y_N = 0 \quad \forall_N$$

In the sales balance equation, it is assumed that the entire crop produced is sold by the end of the cropping season. P_C is the crop price, $SALES_{C, N}$ the quantity of seed cotton sold, $VC_{C,P}$ stands for other variable costs, IP_T the input price, $IPURCH_T$ the quantity of input purchased and Y_N the expected net returns above variable cost.

d. Land constraints

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

$$\sum_{C'}\sum_C\sum_F\sum_P HA_{P, S, C, C', F} \leq BASEHA_{N, S} \qquad \forall_{N, S}$$

The first equation,BASEHA, fixes the total initial number of hectares available to the farmer. It fixes the amount of land that was planted the first year by soil type. The second sets up the limit on the amount of land available that year.

e. Land ratio constraints

$$\sum_C\sum_{C'} BASEHA_{N, S'} * HA_{S, P, C, C', F} - BASEHA_S * HA_{F S' P} = 0 \quad \forall\ P, F, S \neq S'$$

$$\sum_C\sum_{C'} BASEHA_{N, S'} * HA_{S, P, C, C', F} - INHA_S * HA_{F S' P} = 0 \qquad \forall\ P, F, S \neq S'$$

These two equations control for the variable rate fertilizer application strategies under conventional production practices inthe first equation, and FSNM in the second equation.

Summary of indices:

C represents the different crop enterprises or crops (corn, wheat and soybeans)
P is the input management strategy (single or variable rate application)
S represents the three soil types (silt-loamy, clay-loamy and silt)
F is the fertilizer application level (low or medium)
T is the type of input used (fertilizer or pesticide) N is the state of nature

3.2. Data

Data required in the development of the mathematical programming model includes simulated soil specific crop yields, variable production costs and crops' output and input prices. Crops yields were obtained using WinEpic, an interface to EPIC (Erosion-Productivity Impact Calculator). In addition to being an erosion impact calculator, EPIC is also a crop growth simulation model. Crop growth simulation models are capable of simulating crop variables and management practices such 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. WinEpic adds to EPIC a Windows interface, economic data and production practice environment familiar to economists. The EPIC model (Williams et al. 1984) was originally developed in 1981 to conduct a national survey of U.S. agricultural land and determine the relationship between soil erosion and soil productivity throughout the U.S.A. The components of the model include crop growth model, hydrology, weather, erosion, nutrients, soil temperature, tillage, or plant environment control. EPIC was tested and validated in a number of studies (e.g. Williams and Renard 1985; Bryant et al. 1992,Watkins et al. 1998). The model was calibrated to fit Banikoara production conditions. Historical weather and soil database were created and incorporated in EPIC. Fertilizer application rate as well as sowing date data were incorporated into the model in order to replicate the production environment of a typical crop grower in Banikoara. The weather and soil data were obtained from INRAB (Institut National de Recherche Agricole du Bénin). Typical recommendations for planting dates, types, quantity, time and frequency of chemical and fertilizer use were obtained from a survey of local farmers and extension agents.

The model generates expected yields for corn, cotton and sorghum for varying fertilizer levels (nitrogen and phosphorus), and traditional planting dates. Two fertilizer levels were used to generate three series of yield data on three types of soil. The first soil is silt-loamy soil, the second a clay-loamy soil and the third soil a silt soil. For historical reasons most farming units have two to six different fields often in different geographic areas. The medium fertilization level corresponds to the exact recommendations made to farmers by county agents. Yield data using a low level of fertilizer application was also generated because of common practices of application of lower than recommended levels of fertilizer. Crop yields were validated using Banikoara field trial results provided by the agricultural research center (CRA-CF) as well as individual farmers' yield data gathered through the survey. Production budgets were created for each crop to obtain variable production costs. Data were obtained through farmers' surveys, personal communication from county agents and from Adégbidi (2001). Based on production practices and the farm size model in the study, only selected labor costs were incorporated in the budgets. Farm gate output and input prices were collected from the Ministry of Agriculture. Ten years of corn, cotton, and sorghum prices were utilized (Cotlook, Ltd 2012). Finally, precision agriculture cost was estimated based on the FSNM production approach. The scenario assumes a trained county agent in charge of forty farmers. FSNM adoption cost includes the agent's annual income, and the cost of four soil samples amortized over four years.

4. Results and analysis

The current model depicts the production environment of a typical Banikoara cotton farmer. Two models were developed. In the first model the farmer uses traditional uniform rate nutrients on each of his/her fields and in the second model s/he can apply low or medium fertilizer rates on each of three fields. Results from the two models are compared and analyzed. Model statistics results and optimal crop mix and rotation are presented by risk aversion levels .

Table 1. Economic results

Uniform rate application of fertilizer					
	Risk Aversion Level				
	Neutral	Low	Medium	High	Extreme
Mean ($)	$3,580	$3,398	$2,372	$2,147	$2,021
Max ($)	$15,959	$11,620	$5,622	$3,900	$3,223
Min ($)	($527)	($519)	$570	$576	$586
Std. Dev. ($)	$3,552	$3,078	$1,104	$769	$612
C.V. (%)	99.2	90.6	46.5	35.8	30.3
Variable rate application of fertilizer					
	Risk Aversion Level				
	Neutral	Low	Medium	High	Extreme
Mean ($)	$3,457	$3,249	$2,332	$2,097	$1,970
Max ($)	$15,835	$11,381	$5,249	$4,226	$3,183
Min ($)	($650)	($300)	$473	$490	$482
Std. Dev. ($)	$3,552	$2,778	$1,92	$831	$639
C.V. (%)	102.8	85.5	48.1	39.1	32.4

Table 2. Production results

Uniform rate application of fertilizer							
Crop Rotation		Fertilizer Rate	Risk Aversion Level				
1st Crop	2nd Crop		Neutral	Low	Medium	High	Extreme
cotton	cotton	low			4.11	5.02	5.47
cotton	cotton	med					
cotton	sorghum	med			0.79	0.62	0.55
corn	cotton	med	7	6.95	2.1	1.36	0.98
corn	sorghum	low		0.05			
Variable rate application of fertilizer							
Crop Rotation		Fertilizer Rate	Risk Aversion Level				
1st Crop	2nd Crop		Neutral	Low	Medium	High	Extreme
cotton	cotton	low			2.72	3.33	3.63
cotton	cotton	med			1.09	1.33	1.61
cotton	sorghum	med		0.28	0.76	0.69	0.59
corn	cotton	low		2.66	1.04	0.71	0.5
corn	cotton	med	7	3.55	1.39	0.95	0.67
corn	sorghum	low		0.52			

Neutral = 50% risk significance level
Low = 55% risk significance level
Medium = 70% risk significance level
High = 80% risk significance level
Extreme= 90% risk significance level

Net return above variable costs for the risk neutral farmer producing under conventional production practices was $3,580. This figure represents a two years income for the hypothetical Benin cotton farmer producing 7 hectares.It also includes the value of family labor and all fixed equipment costs (plowing equipment, animal purchase and maintenance cost as well as all small equipment's cost). The net return as modeled also assumes that the farmer sells all his/her production at market value. In reality, a large portion of the corn and the sorghum (when it is produced) is kept for family consumption. The optimal crop rotation for the risk neutral farmer was corn and cotton produced using medium level of fertilizer application. As risk aversion increases however, the farmer's production strategy changes as well. The medium risk averse producer could obtain a net return of $2,372 with a maximum attainable return of $5,622 and a coefficient of variation of 46 percent. That farmer allocates 57 percent of his/her available land to the production of continuous cotton with a low rate of fertilizer application, and his/her income is only 66 percent of that of the risk neutral producer. The acreage allocated to continuous cotton rotation increases as risk aversion increases. This production strategy was also found to be a common practice in the region. All the farmers surveyed adopting this risk aversion strategy and representing the majority of farmers surveyed, are fully aware of the financial penalty associated with their risk aversion behavior and production decisions. Producing cotton in continuous rotation in spite of the financial and ecological penalty is motivated by aversion to income variability, but not only that. By producing cotton, farmers are guaranteed to have their production sold, and the money received as a lump sum. In his thesis, Bradley (2002) found (out of 101 farmers interviewed) that 73.3 percent of farmers viewed cotton as the most important crop for the family; fivepercent chose corn, 18.8 percent sorghum/millet and 3 percent peanuts. He also found that cotton remains, for farmers, a very important crop, even with regard to food security, because it is the only crop with an organized market.Ninety nine percent of the farmers interviewed say that they would be interested in alternative crops. Selling corn or sorghum involves long trips to local or regional markets while exposing the farmer to full marketing risk. In addition, the crop is sold over a longer time period with the money coming in smaller increments, making it, for them, more difficult to save and make important investments. Finally, there is a social recognition that comes with the quantity of cotton sold.

Results here show that variable rate fertilizer application results in higher yield compared to the conventional method. However, given the relatively high cost of adoption for local conditions, net returns associated with FSNM adoption was lower than that of conventional practices. For the risk neutral FSNM adaptor, net return was $3,457, only 4 percent lower than the return in the conventional case. Therefore, limited governmental support could render FSNM profitable. This result can also in part be explained by the fact that there are only two levels of nutrient application rate in the model allowing for less flexibility. FSNM would also have been more profitable under a different set of assumptions. The very conservative approach used here included the FSNM service provider income in the technology cost. The difference in the expected net return between FSNM and traditional production practice narrows as risk aversion increases. However, FSNM adoption slightly increases income risk as it results in a higher c.v. compared to uniform rate fertilizer application. [insert table 2 here]

Production strategies for FSNM were different from the ones obtained with conventional practices for risk averse farmers, but identical for risk neutral ones. These differences are important in the sense that adoption of FSNM allows the farmer to diversify. First, the proportion of available land area allocated to continuous cotton production (75 percent) was smaller than in the conventional case (78 percent). Usage of a higher level of fertilizer application not only is more profitable, exception being made of the technology cost, but also will be likely to reduce the incidence of soil depletion and, ultimately, the need for farmers to move away from their villages in search of new land.

5. Conclusion

From this study, it can be concluded that PA could indeed be adopted by most of Benin cotton producers but the adoption of such a technology will require some level of government involvement. Though not more profitable than uniform rate application, FSNM increased yield and production. However, there is not a substantial difference in net returns between VRA and conventional production (net returns for conventional production was 3% higher than that of VRA), signaling that the gain in increased yield was almost entirely absorbed by the technology cost. In the case of limited government involvement through a full of partial support of county agents, the adoption of the new technology will prove profitable and increase farmers' disposal income. In addition, FSNM adoption through increased fertilizer use at an optimum level could help reduce soil depletion. Technology cost and availability of qualified personnel will remain an obstacle to adoption in Benin.

At the production level, FSNM has no major impact on the production strategy adopted by risk neutral farmers. It did not change the crop rotation strategy adopted by farmers. Cotton remains in the rotation in almost all scenarios for the risk neutral farmer but was never produced in continuous rotation, indicating that the observed phenomenon of continuous cotton production is mainly the fact of risk averse farmers.

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