Monsanto's Adventures in Zulu Land: Output and Labour Effects of GM Maize and Minimum Tillage

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Abstract: *The only commercial genetically modified (GM) subsistence food crop is white maize in South Africa, which was released in 2001/2. This paper reports on the performance of insect resistant (Bt) white maize grown by smallholders in Hlabisa, KwaZulu Natal, where the other development is minimum tillage. The results show that, contrary to many inflated claims, in the dry 2003/4 season, there was no significant difference between the yield per kg of seed for Bt and conventional maize, due to very low stalk borer infestation levels. Farmers who planted Bt maize in 2003/2004 were thus worse off as they paid more for seed and obtained no benefit. This is measured using efficiency scores from a stochastic frontier analysis. These results conflict with the yield per hectare figures, which show a gain of 25% from using Bt. We think this shows that kgs per hectare is not a meaningful performance measure for African smallholders. More interesting is the effect of minimum tillage, which apart from reducing erosion, increased yield per ha by 12%, while reducing costs and increasing efficiency by 9%. But the saving is in reduced labour, which may not be an advantage if jobs are lost.*

> ***Alice: "Would you tell me, please, which way I ought to go from here?"***
> ***Cheshire Cat: "That depend a good deal on where you want to get to."***
>
> ***Alice's Adventures in Wonderland***

JEL Codes: O33, Q16

1. INTRODUCTION

This study reports on a survey of semi-subsistence maize production in a poor area of KwaZulu Natal, conducted in 2003/4. It concentrates on the output and employment impacts of insect resistant Bt maize as well as minimum tillage, which is also being used in the area. The impact on performance is measured by simple partial productivity indices, which are output per kg of seed, per hectare of land and per hour of labour. The total, or overall effect is captured by comparing farm level efficiencies, relative to best practice, as represented by a stochastic production frontier. The results serve as an antidote to the enthusiasm generated by huge gains in trial plot yields. The Bt seed increases yields by 25%, but this is not attributable to superior seed, as output per kg of seed is exactly the same as for conventional seed. Nor is there any difference in labour productivity and due to the higher cost of Bt seed the adopters are actually 3% less efficient. By contrast, minimum tillage raises yields by 12% and increases efficiency by 9%, because it practically doubles labour productivity.

The paper proceeds as follows. The next section describes the region, reviews the salient features of maize production using summary statistics and describes the data used in the estimation. Section three outlines the stochastic frontier model with inefficiency effects and reports the results of the hypothesis tests for model selection and the stochastic frontier results. The fourth section analyses the output performance of the two technologies and their impact on labour use. This is followed by a brief conclusion.

2. GM MAIZE AND MINIMUM TILLAGE: SUMMARY STATISTICS AND VARIABLE DEFINITIONS

Hlabisa is situated just above the Umfolozi game reserve, which is between Mtubatuba and Ulundi in north-eastern KwaZulu Natal. The area has an annual average rainfall of more than 980mm, with 85% of the rain falling during the production season. As much as 75% of harvested maize grain is kept for household consumption and chicken feed, which is indicative of the level of poverty in the region. Farmers cannot afford milling costs and use a hammer mill or crush their grain in a traditional way to consume the maize as samp (stampmielies) with beans or with milk (amarhewu). The majority of households in the area own a small, old hand mill where maize can be milled into different degrees of fineness.

The government extension officers have been recommending minimum tillage for some time, due to local erosion problems. Bt maize has also been in use since trials began in 2001/2, when small quantities of free seed were supplied to the farmers. In 2003/4 our survey covered 135 farms, and collected data on household characteristics, income, expenses, consumption, farming practises, production budgets and seed performance. The survey concentrates on accurate measures of yield, including green mealies, which are eaten over the season, before the main harvest, and especially on labour use.

There are complete records for all 135 producers, of whom 48 planted Bt only, 25 adopted minimum tillage, two did both and 62 did neither. Farmers were surveyed with the help of enumerators who know the area and the farmers, and who had already been trained through their involvement in previous studies. Each respondent was visited seven times during the course of the season, as follows:

TABLE 1 HERE

The initial visit to each household in November/December entailed the collection of a significant amount of household information, in addition to the labour data and input use for the first maize land preparation and planting activities. During a visit in February, information was collected on pest incidence and on quantities of green mealies harvested, in addition to the ongoing collection of data on labour and input use. Previous studies showed that the March-May period is rather quiet, with few required activities. The major labour-using periods are during land preparation and planting and the first six weeks after planting for weeding and pesticide application. In May and June, data was collected on the quantities of maize harvested, again in addition to the ongoing labour data.

Table 2 reports the summary statistics for the sample, in terms of the variables used in estimation. Output is in kgs of maize, with an average of 401 and a wide dispersion.

Land area is in hectares, with an average farm size of only 0.378 hectares and even the largest farm is under 5 hectares. The farmer's own estimates of the size of their plots were hopelessly inaccurate, gross over-estimates, with an average of 1.62 hectares, or over four times the measured areas. This bodes ill for studies that rely on information provided by farmers. Total labour is also measured in physical units, in this case, hours. The other production inputs are land preparation, seed and fertilizer costs, all measured in Rand. The land preparation costs are an aggregate of very different inputs: for the minimum tillage farmers, it is herbicide costs: for others it is the cost of hiring a contactor to plough: for the rest it is the costs associated with preparation using donkeys or oxen, or own tractor use (only 3), or hand hoeing (skoffel). Seed cost is used rather than quantity, to allow for the fact that Bt seed is roughly twice as expensive. Fertiliser varies too, so it is included as a cost rather than a quantity.

TABLE 2 HERE

The last two variables are farm-specific factors that are used to explain the efficiencies in the second part of the model. The first is household size, measured as number of persons and the second is the number of months that the household managed to support itself with the last maize harvest.

3. CHOICE OF MODEL, FUNCTIONAL FROM AND RESULTS

3.1. The Model

The survey by Battese (1992) shows that fitting frontier production functions to agricultural data has become common. Stochastic frontiers, of the type originally suggested by Aigner, Lovell and Schmidt (1977), discriminate between random errors and farm level differences in efficiency. Battese and Coelli (1995) introduced the inefficiency model, in which the efficiency differences are simultaneously estimated from the stochastic frontier and explained by farm-specific variables. Their models incorporate tests that choose between functional forms and between frontier and mean regression models.

The general form of the production frontier is

$$Y_i = \alpha + \sum_j \beta \, x_{ij} + \varepsilon_i \quad where \; \varepsilon_i = V_i - U_i \qquad \textbf{1}$$

$$with \quad U \sim |N(0, \sigma_U^2)| \quad and \quad V \sim N(0, \sigma_V^2)$$

The V_i*'s* are independently and identically distributed random errors and uncorrelated with the regressors, and the U_i's are non-negative random variables associated with the technical inefficiency of the farm.

The technical efficiency of an individual farm is defined in terms of the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by that farm. Thus, the technical efficiency of farm *i* in the context of the stochastic frontier production function is defined

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(x_i : \beta)\exp(v_i - u_I)}{f(x_i : \exp(v_i)} = \exp(U_i) \qquad \textbf{2}$$

In Battese and Coelli's (1995) inefficiency model, the U_is, in equation (1) are defined as

$$U_i = z_i \delta + W_i \qquad \textbf{3}$$

where z_i is a vector of explanatory values associated with farm level technical

inefficiencies in production, δ is a vector of unknown parameters to be estimated and W_is are the errors. First, the functional form of the stochastic frontier is determined by testing the adequacy of the Cobb Douglas relative to the less restrictive translog. These frontier models are defined as
where all of the variables are in logarithms and if terms under the double summation

$$Y_i = b_0 + \sum_{j=1}^{n} b_j x_{ji} + \sum_{j=1}^{n}\sum_{k=1}^{n} b_{jk} x_{ji} x_{ki} + V_i - U_i \qquad \mathbf{4}$$

are not significantly different from zero, the translog reduces to the Cobb Douglas. Y is maize output in physical terms and the independent variables (x_i) are land, labour, land preparation costs, seed costs and fertiliser costs. This gives twenty independent variables in the translog due to the addition of five squared terms and ten cross product terms. There are also two dummy variables, for minimum tillage and Bt seed, in order to determine the basic impact of these technologies. In the inefficiency model, there are four explanatory variables, which are household size, self-sufficiency in maize, education (three levels) plus one more dummy, which was whether the household sold labour services during the period.

3.2. Hypothesis Tests

First, a series of hypothesis tests were conducted to select the functional form and to choose between the frontier model and the standard average production function. The results reported in Table 3. Tests for the preferred functional form are the null hypothesis (H0) is that $\beta_{ij} = 0$, i,j = 1,...,n, meaning that the Cobb-Douglas frontier is an adequate representation for these data. Generalised Likelihood Ratio (LR) tests[1] show that this hypothesis is accepted as the test statistic is well below the critical value.

TABLE 3 HERE

Having selected the Cobb Douglas functional form, the next section of Table 3 reports the results of tests of the hypothesis that the technical efficiency effects are not simply random errors. The key parameter is $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$, which is the ratio of the errors in equation (1). So, γ is defined between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and if $\gamma = 1$, there is no random noise. The null hypothesis is thus that $\gamma = 0$, indicating that the mean response function (OLS) is an adequate representation of the data, whereas the closer γ is to unity, the more likely it is that the frontier model is appropriate. If γ is not significantly different from zero, the variance of the inefficiency effects (W_i in equation 3) is zero and the model reduces to a mean response function in which the inefficiency variables enter directly (Battese and Coelli, 1995). This test is unambiguous, with the value close to unity and the t test indicating that the frontier is the appropriate model. The next column in this section reports the LR test values for the more powerful test with the null hypothesis that $\gamma = \delta_0 = \delta_i = 0$, which means that in addition to γ being insignificant, the inefficiency effects are not present in the model. The null hypothesis, H_0, can be rejected at the 5% level, with degrees of freedom equal to the numbers of parameters set to zero.[2]

[1] The likelihood-ratio test statistic, $\lambda = -2\{\log[\text{Likelihood } (H_0)] - \log[\text{Likelihood } (H_1)]\}$ has approximately χ^2_v distribution with v equal to the number of parameters assumed to be zero in the null hypothesis.

[2] As the null hypothesis involves parameter γ, which as a ratio of two variances is necessarily positive,

3.3. Results

The Cobb Douglas function was found to be an adequate representation of the unknown, underlying production function, meaning that the cross products and squared terms did not improve the fit sufficiently to justify inclusion. Table 4 reports the parameter estimates and t statistics for these models, beginning with the output elasticities for the inputs. Land and labour, which are the essential inputs, are both significant at the 1% level and both have elasticities of 0.2, meaning that a 1% increase in either will increase output by 0.2%. The surprising result is the impact of the seed, which has an elasticity of 0.71 and thus has the biggest impact. Indeed, the composite land preparation cost elasticity is very small and not significantly different from zero and neither is fertiliser. Not all the farmers use fertiliser and most use too little, which may account for this result.

TABLE 4 HERE

The dummy variable for minimum tillage is positive and significant at the 10% level, indicating that this technology does increase output, as well as cutting soil erosion, which was the way it was introduced. However, the effect of Bt is negative and insignificant, which is at odds with almost all the previous studies of Bt cotton and maize in South Africa, such as Thirtle et al. (2003) and Gouse et al. (forthcoming).

The four variables that explain the inefficiencies are reported last. In the model, selling labour is not a cause of (in)efficiency and neither is education, but the significantly negative effect of household size means this reduces inefficiency and the same is true of self sufficiency. However, the causality may well be that the households that are more efficient achieve greater self sufficiency.

4. Analysis of the Production and Labour Use Impacts of Bt and Minimum Tillage

4.1. Output Effects

The impact of the two new technologies on output is considered next and is indeed the main point of the paper. The simplest partial productivity measures are analysed first in Table 5, beginning with output per hectare, with the area planted measured by our enumerators. The results show that for the full sample the average yield is 1130 kg, which is normal for these types of farms and only about half the two to three tonnes that the extension workers would like to achieve. The Bt average is 1392 and 38% higher than that for the non-Bt farms, which is 1007 kg. This is frequently the only performance measure reported, for instance in the analysis of trial plot yields. The question is, does this really mean that Bt is valuable to these farmers?

TABLE 5

Column two reports the yield per kg of seed, which is a far more meaningful statistic for semi-subsistence farmers. It shows that the Bt seed, which costs about 50% more, gives the same output as conventional seed. For the farmers this is the test, not yield per hectare that is anyway hard to measure. The difference between output per hectare and output per kg of seed is explained by the planting density, shown in

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the test statistic follows a mixed chi-squared distribution and the critical values are from found in Kodde and Palme (1986). The odds against the test statistic being the same as the critical value at three decimal places are so huge that this note is included to explain that the reported result is not an error.

column three. This must be true as Q/A ≡ Q/S*S/A is an identity and indeed column three shows that S/A is 37% higher for the Bt fams.

This poor performance is the result of very low pest pressure in this particular year, as in the previous season Bt yielded 16.8% more per kg of seed (Gouse et al., forthcoming). Farmers selling the additional grain enjoyed an R39.00 income increase, but food deficit households gained R210. Thus, the poorest farmers, who are replacing purchased maize meal with the extra Bt maize that they produce, benefit the most. This demonstrates the need for more than one year of data.

The next column shows that Bt uses the same amount of labour as conventional seed, which is also a function of the low pest pressure. All else being equal the Bt seed should have saved labour used to spread pesticide granules, but there was so little damage that there is no significant effect. The last column avoids the partial measures, which can obviously be misleading and uses instead the efficiencies, which are a total measure, in that they take all the inputs into account. Here, the higher cost of the Bt seed and its failure to increase output or reduce labour in this low pest pressure year is reflected in a 3% lower efficiency level for the Bt farmers. This is due to the cost of the Bt seed, which can be established by running the model with seed quantity instead of cost. If this is done, there is no efficiency difference between Bt and conventional seed.

The other new technology is minimum tillage, which is analysed in the last rows of Table 5. Although the main objective of the extension agents in recommending minimum tillage was to reduce erosion, the first column shows that it actually increased yield per hectare by 12%, which was not expected. In contrast with Bt output per kg of seed increased by 15%, at no extra cost to farmers, as the next column shows that the seeding rate was no higher. In this case, the yield gain is combined with a 98% increase in labour productivity, which is enough to give the overall efficiency advantage to minimum tillage of 9%, shown in the last column.

4.2. Employment Effects

The impact of GM crops on employment has attracted little attention to date, but this survey made a point of repeated visits in order to gather reasonably accurate labour input data. Our experience with labour data based on farmer recall at the end of the season suggests margins of error as big as those for area planted. The data are reported in Table 6 according to task and the last column shows that the average farm used 249 hours of labour. The Bt technology is neutral with respect to labour use, but the minimum tillage technology reduces the labour input by a massive 57%. The breakdown shows labour savings across all tasks, but especially in land preparation and weeding, which is to be expected.

TABLE 6

It is fortunate that this labour input reduction has been recorded in this year, as in the present season, minimum tillage is being adopted in conjunction with Roundup Ready white maize. This is a herbicide tolerant GM crop, that is immune to the herbicide Roundup, allowing more effective weed clearance without deep ploughing. However, the results reported here indicate that the labour saving bias, which is inevitable, is attributable to minimum tillage, not the new GM technology.

5. Conclusions

This paper reports the results of analysing a survey of smallholders growing maize in Hlabisa, KwaZulu Natal, using both Bt and minimum tillage. The first result of note is that although the output per hectare for Bt is 38% higher, the output per kg of seed is the same as for the conventional seed. This suggests that for African smallholders, yield may not be a suitable measure of performance. They are usually more concerned with output per kg of seed, especially when it is expensive Bt seed. The second point is that a single year is not adequate for measuring performance. In this low pest pressure year, Bt gives no advantage and because of its higher cost causes the adopters to be inefficient relative to best practice. This shows the need for several performance measures, based on estimates by trained enumerators and more than one year of data.

On the other hand, minimum tillage, which was introduced to reduce erosion, does give both higher yields and higher efficiency levels. In this case, the yield gain of 15% per unit of seed is secondary to the main effect, which is saving in labour of 57%, which makes the minimum tillage more efficient than any alternatives. However, this may not be an advantage, as many development economists would expect that less labour use results in lower incomes for the poorest, whose incomes depend on selling labour services. This was always taken to be the case in labour abundant Asia, but in SSA it is not obvious that land is the scarce resource. Hence, maximising yields may not be the objective and indeed labour productivity may matter more. This was perhaps true even before HIV/AIDS, which in an area like this may affect as much as 40% of the labour force. If, like Alice, Monsanto asked which way to go, it is not clear we can answer any better than the Cheshire cat. With this in mind, we are wary of making any pronouncement on the suitability of labour saving technology. It may be that minimum tillage, which is now being combined with herbicide tolerant GM maize, will alleviate family labour shortages rather than reduce wage labour. Putting children into school, instead of subjecting them to the drudgery of weeding is hardly a bad idea.

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Table 1: Schedule of Visits

Month	Activities	Visits
October	Start-up meeting, training of enumerators, identify farmers	1
November 03	Land preparation, planting (+basal fertilizer), herbicide	3
December 03	Weedings(s), top dressing, cutworm control	
January 04	Weeding, stalk borer control	
February 04	Weeding, green mealie harvesting	1
March 04	green mealie harvesting	
April 04	Quiet	0
May 04	Harvest	2
June 04	Harvest	
TOTAL		7

Table 2: Summary Statistics for the Samples

	Output kg	Area ha	Labour hours	Land Preparation Rand	Seeds Rand	Fertiliser Rand	Household Size Number	Maize Sufficiency Months
Average	401	0.378	249	229	194	135	10	7
Minimum	46	0.012	37	0	34	0	1	0
Maximum	2660	4.475	1116	950	680	625	25	16

Table 3: Hypothesis Tests

Functional Form Test	Log-Likelihoods		LLR Test	DOF	χ^2_{15} Critical	Outcome
Parameter Restrictions	H0: Cobb Douglas	H1: Translog	Statistic		Value 5%	
H_0: All $_{jk} = 0$	-97.39	-90.34	14.1	15	25.0	Accept H0 - CD is adequate
Frontier Tests			LLR test		Parameter Restrictions: H_0: $\gamma = \delta_i = 0$	
	Gamma	t stat	Statistic	DOF	Critical Value	Outcome
	0.999	114.951	11.911	6	11.911	Reject H0 - frontier not OLS

Table 4: Stochastic Production Frontier and Inefficiency Model Results

Frontier Model	Intercept	Land	Labour	Land Prep	Seed	Fertiliser	Minimum Tillage	Bt
Coefficient	2.429	0.203	0.205	-0.027	0.714	0.032	0.232	-0.059
t-ratio	4.357	3.911	2.686	-0.861	7.606	0.887	1.668	-0.553
Inefficiency Model	Intercept	Sold Labour	Education	Family Size	Self Sufficiency			
Coefficient	1.558	0.114	0.071	-0.025	-0.030			

t-ratio	11.524	0.788	1.392	-2.369	-3.136			

Critical values for a one tailed test are 10%, 1.282: 5%, 1.645: 2.5%, 1.960, 1%, 2.323

Technology	Output per hectare, kg	Output per kg of seed	Kg of seed per hectare	Output per hour of Labour	Efficiency: from Stochastic Frontier
	Q/A	Q/S	S/A	Q/L	
All farms	1130	57.18	19.76	2.114	0.3766
Bt only	1392	57.75	24.10	2.095	0.3687
Non Bt	1007	56.87	17.70	2.125	0.3810
Minimum Tillage	1234	63.97	19.28	3.544	0.4041
Non Minimum Tillage	1107	55.74	19.86	1.789	0.3704

Table 5: Analysis of Performance

Table 6: Analysis of Labour Use Impacts

	Land Preparation	Planting	Weeding	Herbicide Application	Top Dressing	Pesticide Application	Harvesting	Total Labour
All	36	40	114	11	18	6	90	249
Bt	37	38	95	12	0	0	102	251
Non Bt	35	41	126	11	18	6	83	248
MT	10	26	34	12	7	4	70	120
Non MT	42	43	122	8	35	6	94	279