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ECONOMICS OF THE GREENSEEDER HAND PLANTER

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Abstract

Corn (*Zea mays* L.) is an important staple food crop for millions of people in many developing countries. Its production levels in developing countries, are lower than in developed countries in part to planting methods that involve hand dropping of multiple seeds per hill assisted with tools such as hand hoes, cutlasses and/or dibblers (Stick Seeder Planter (SSP)). Researchers at Oklahoma State University (OSU) developed the Greenseeder Hand Planter (GHP) which is hypothesized to reduce optimal seeding rates because it places one seed per hill and potentially reduces long term health risks because it does not require using bare hands to drop the pesticide treated seeds. The objective of this research was to determine the economics of using the GHP relative to the conventional SSP. Data from field trials were obtained. A linear mixed effects model was used. Partial budgets were used to determine the quantity of seed savings, the amount of labor, and the increase in corn yield that would be required for the GHP to be an economically viable alternative to the SSP. Results suggest that a GHP expected to be used to plant 3 hectares per year that costs $50 would be required to increase corn yields by 0.028 Mg per hectare or save about 9,022 seeds per hectare (12.19% less) to equal expected net returns from the SSP. Alternatively, it would be required to reduce labor man-days by 1.933 for a farmer to breakeven relative to the SSP. Additional research would be required to determine differences in farmer health consequences of the GHP relative to the SSP from the reduction in the level of contact with pesticide treated seed.

Key Words: Corn, Greenseeder Hand Planter, planting by hand, linear mixed effects, partial budgeting.

JEL Codes: Q13, Q16

1.0 Introduction

Corn *(Zea mays* L.) is one of the most cultivated crops in the world. Since its origins from Mesoamerica, corn is produced throughout the world. It can be grown over a wide range of altitudes and latitudes (Shiferaw et al. 2011). Plant breeders have developed varieties with abilities to grow under different biophysical environments. Thus, global corn production has increased over the years. Between 1961 and 2010, area allocated to corn production increased by more than 50% with about 73% of this growth in developing countries (Shiferaw et al. 2011). In 2010, corn was planted on about 73%, 44%, and 46% of the cultivated land in Africa, Latin America and South Asia, respectively (Shiferaw et al. 2011) and on 35 million USA hectares (USDA 2016*).*

While demand for corn in developing countries remains high (Borlaug 2007; Shiferaw et al. 2011), its yields in developing countries are lower than in developed countries (Cairns et al. 2013; Chim et al. 2014). For example, since 1961 corn yields in the top five corn producing countries in the world (USA, China, Brazil, Mexico, and Indonesia) have increased three-fold (from 1.84 Mg ha^{-1} to more than 6.10 Mg ha^{-1}) while in developing regions of Africa, Asia and Latin America, corn yields have stagnated at less than 2 Mg ha^{-1} (FAO 2011; Cairns et al. 2013)[1]. These yield differences are attributed to a number of factors including access to and use of localized seed genetics, fertilizer, pest management, and differences in seeding practices (Adjei et al. 2003; Aikins, Plange and Baffour 2010; FAO 2007). In developed countries, mechanized planters that deliver and cover single seeds per drop at relatively precise depths and precise within row spacing, enhances yield potential (Omara et al. 2015; Mukembo et al. 2016). But,

[1] By 2016, current average corn productivity in the U.S is at least 10 Mg per hectare (USDA 2016)

about 60% of corn area (29 million hectares) in developing countries is planted with multiple seeds per hill by hand (Mukembo et al. 2016*;* Chim et al. 2014; Fisher 2016).

Planting by hand usually involves using a heavy Stick Seeder Planter (SSP) and/or hand hoe. Workers use the SSP to open a shallow hole about 5 cm deep; drop two to three seeds in the hole; cover the seeds with soil forming a small hill; and step on the hill enhancing soil to seed contact (Adjei et al. 2003). The typical SSP is composed of a wooden shaft and a pointed metal tip that can be used to penetrate the soil and open a slot for seed placement (FAO 2010). Aikins, Plange and Baffour (2010) explain that the whole process is labor intensive and results in non-uniform plant stands often with multiple plants emerging from each hill and competing for nutrients. For equivalent seeding rates, non-uniform spacing of seeds has been found to result in lower yields than uniform spacing (Epplin et al. 1996; Rutto et al. 2014). Nafziger, Carter and Graham (1991) and Martin et al. (2005) argue that planting methods that do not homogenize distance among corn plants increase plant-to-plant variation and nutrient competition resulting in decreased grain yields.

The two major variable cash cost items for hand seeded corn production are seed costs and fertilizer costs. For example, the typical seeding rate for Zambia is about between 70,000 seeds per hectare at a cost of about $37.5 per hectare (Zambia National Farmers' Union (ZNFU), 2015). Expected cost of fertilizer is $190 per hectare. If planting a single seed per hill with a GSP relative to multiple seeds per hill with a SSP reduced the number of seeds required for optimal yields per hectare by 20%, seed cost savings could amount to $7.5 per hectare (Duncan 1984). Theoretically, use of a GHP relative to a SSP could result in equivalent or greater yields from fewer seeds purchased and planted per hectare.

The GHP includes a seed box that eliminates the need for the operator to handle each seed (see Figure 1). Prior to planting, corn seeds are commonly coated with one or more pesticides such as imidacloprid (trade name Gaucho), permethrin (trade name Kernel Guard Supreme or Profound), thiamethoxam (trade name Cruiser), as well as with biological agents (Paulsrud et al. 2001). Careless handling of coated seeds may result in deleterious health consequences. Thus, the GHP is hypothesized to reduce long term health risks because it would reduce operator exposure to treated seeds (Fisher 2016).

The GHP is designed to release a single seed per location which is intended to improve homogeneity of plant growth, decrease inter-plant nutrient competition, improve yield potential, and reduce seed cost per hectare (Chim et al. 2014; Fisher 2016). However, research is warranted to determine the effect of the GHP on corn yields as well as how much labor savings, seed savings, and corn yield increase would be required for the purchase and use of the GHP to produce equivalent returns as use of the SSP.

Therefore, our study seeks to determine the economics of the GHP. Specifically, we determine the effect of using the GHP on corn yield per hectare relative to conventional SSP hand planting. We also determine the amount of labor savings, seed savings, and the quantity of corn yield increase that would be required for purchase and use of a GHP to be an economically viable alternative to the SSP. Evaluation of the GHP technology could result in important findings for farmers producing a vitally important food crop. We achieve these objectives by employing a linear mixed effects model and partial budgeting techniques to findings from designed field trials in which the GHP and SSP were used.

2.0 Theory

Before the planting season, farmers must decide what planting method to use. They are expected to choose the planting method that maximizes expected net returns and improves their welfare. Biermacher et al. (2009) suggest that the expected profit maximizing framework is suitable to model behavioral decision and choice of farmers before the onset of the planting season. Assume that one of the farmers' objectives is to adopt a planting method that maximizes expected profit π_i by comparing profit that is yielded by *m* alternative methods. The farmer chooses a planting method *j* over any alternative package *m* such that

(1) $$\pi_j > \pi_m, m \neq j.$$

The adoption decision D^* and the optimal expected profit π_i^* from choosing a given planting method would be unobservable and thus the farmer's choice of the planting method would be:

(2) $$D^* = \begin{cases} 1 \text{ iff } E(\max E(\pi_{ij}^*)) > E(\max_{m \neq j} E(\pi_{im}^*)) \text{ or } \eta_{i1} > 0, \text{for } \forall m \neq j \\ 0 \text{ otherwise} \end{cases}$$

where $\eta_{ij} = E(\max_{m \neq j}(\pi_{ij}^* - \pi_{im}^*)) > 0$ (Bourguignon, Fournier and Gurgand 2007; Biermacher et al. 2009). By eqn. (2), a farmer whose objective is to maximize expected profit is expected to adopt a planting method whose expected profit is greater than all alternatives. The GHP considered here is hypothesized to drop a single seed per planting station as opposed to an SSP in which two or more seeds are dropped per hill. Thus, if the same number of seeds are planted per hectare, the theoretical expected yield would be greater for the GHP given the expected agronomic benefits of uniform plant spacing. Alternatively, if fewer seeds are planted per hectare with the GHP, total seed costs would be lower. Ignoring the potential value of farmer health benefits of using a GHP relative to a SSP, the farmer's optimization problem is mathematically

(3) $$\max_D E(\pi_i) = ((D)(pE(y_{GHP}) - c_{GHP}) + ((1 - D)(pE(y_{SSP}) - c_{SSP}))$$

subject to

$$y_k = f(\boldsymbol{x}),\ k = \{GHP, SSP\}, \quad D \in \{1,0\},$$

where p is the price of corn, $E(\pi_i)$is expected profit ($) per hectare, D is the treatment dummy variable, equals 1 if the farmer uses GHP, 0 otherwise, $y_{GHP}$is corn yield from plots where the GHP was used, y_{SSP} is corn yield from plots where the SSP was used, c_{GHP} is cost of production from plots where the GHP was used, c_{SSP} is cost of production from plots where the SSP was used, $y_k$is corn production function and $\boldsymbol{x}$ denotes a vector of inputs used in corn production.

3.0 Data and Procedures

Agronomic

Agronomic data were generated from experiments conducted at the Efaw, Lake Carl Blackwell and Stillwater Agronomy Research Stations in Payne County, Oklahoma, USA. Efaw is located on an Ashport silty clay loam soil. The Lake Carl Blackwell plots are composed of Pulaski fine-sandy loam soils. Stillwater Agronomy Research Station has mostly Kirkland silt loam soils (Omara et al. 2015). These experiments were designed as randomized complete blocks. Each experiment comprised three replications and four plots per replication in each site year. The experiments were conducted at the Stillwater site in 2014, at Efaw in 2014 through 2016 and at Lake Carl Blackwell in 2015 and 2016.

Treatments consisted of planting methods: GHP, SSP, and a tractor drawn John Deere Planter (JDP). The GHP has an internal drum that can hold up to 1 kg of seed. It was designed to deliver a single seed per hill at a planting depth of about 5cm (Omara et al. 2015). The SSP has a metal tip like those typically used in Central and South America. Its only function is to open a planting hole into which seeds are dropped and covered by foot (Chim et al. 2014).

{Table 1}

Hybrid corn variety Pioneer P1498HR was planted on all plots with plant population of 74,000 seeds per hectare. Inter-row spacing at all the stations was 76 cm while plant spacing was uniform at 18 cm. Plot size varied ranging from 1.5 m by 6 m to 3 m by 6 m. Summary statistics of corn yield from each research station are shown in table 1 while summary statistics from the research stations according to planter type are shown in table 2.

{Table 2}

Economic analysis

Partial budgeting was used to determine the economics of the GHP. A farmer's decision to adopt a GHP would result in incremental changes at the farm and a partial budget is a useful tool for a farmer when such a situation arises. Partial budgeting is a powerful and useful technique as it reveals to the farm manager possible tradeoffs and the viability of adopting a given technology (Nuthall 2011). It is useful at depicting their financial effects by considering only parts of the farm business that would be affected. The overall impact is computed by netting out the negative effects from positive effects. Positive effects include the monetary value of activities that would increase revenue and/or decrease costs while negative effects are those that would decrease revenue and/or increase costs. In our partial budget, the added returns were the additional revenue that would result from using the GHP and reduced costs were assumed zero since the change in seeds and labor was considered in added costs. The added costs also included annual operating costs whose computation relied on depreciation, interest on average value, repairs, taxes, and insurance (also called the DIRTI-5 by Lessley and Holik 1987). Reduced revenues were zero.

The following assumptions were used in our partial budget analysis. The market price of the GHP would assumed to be $50 per unit with a useful life of 3 years assuming it would be used to plant corn seed on up to 5 hectares per year. An annual market interest rate of 6% was assumed while the repairs, taxes, and insurance for the GHP are assumed to be zero. Price of corn is assumed to be $175 per Mg while labor cost was set at $2.5 per man-day. A farmer is assumed to plant a hectare of corn up to 5 days while 25 kg of corn seed is assumed to be planted on one hectare of land. These assumptions and variable values were pulled from the standard nationally representative smallholder corn enterprise budget from Zambia. The corn enterprise budget was prepared by the Zambia National Farmers Union (ZNFU) based on production practices by representative Zambian smallholder corn farmers in 2015 (ZNFU, 2015). Zambia is a developing country in sub-Saharan Africa (SSA) where the SSP is common (Haggblade and Tembo 2003). In addition, Zambia is one of the countries where the GHP has been distributed (see Figure 2).

Statistical analysis

To determine the effect of using GHP on corn yield, a separate model is estimated. Our data are cross-sectional time series and therefore could be prone to problems of non-spherical errors across seasons. We therefore use the R-package lme4 (Bates et al. 2015) to estimate the linear mixed effects model. The R-package lme4 is appropriate because it uses restricted maximum likelihood estimation (also called residual maximum likelihood estimation) (REML). For estimation of linear mixed effects models, REML is preferred to maximum likelihood estimation (MLE) because it yields unbiased covariance parameters by accounting for the loss of degrees of freedom that results from parameter estimation of fixed effects (West, Welch and Galecki 2007). To determine the statistical significance of treatment main effects, we used the R-package lsmeans developed by Lenth (2015). Our linear mixed effects model's data generating process is

(3) $$y_{itk} = \mu + \tau_i + s_t + \varepsilon_{itk}$$

where y_{itk} is corn yield from kth site in year $\text{site} - \text{year } t$ where the ith planting method was used, μ is overall mean, $\tau_i$is effect from ith planting method, $s_t \sim N(0, \sigma_s^2)$ is the site-year random effect, $\varepsilon_{itk} \sim N(0, \sigma_\varepsilon^2)$ is random error, σ_s^2 and $\sigma_\varepsilon^2$are mutually independent.

4.0 Results and Discussion

Several diagnostics were conducted to determine the plausibility of the liner mixed effects model selected. Based on the Shapiro-Wilk test, the null hypothesis of normality of the distribution of corn yield was not rejected at a 10% significance level (p-value=0.02). Since the data were unbalanced, to account for any potential deviation from normality, the Levene test was used to check if corn yield variances across the three treatments were constant. The Levene test is robust against serious departures from normality, and does not require balanced sample sizes (Freund and Wilson 2003). Based on results from the Levene test, the null hypothesis of equal corn variances across the treatments was not rejected (p-value= 0.567). The likelihood ratio test was used to determine significance of the fixed effects (based on the ANOVA function in R software) in the model. The null hypothesis of absence of the fixed effects was rejected (p-value < 0.001). Parametric bootstrap of the p-value based on 1000 replications was used to determine statistical significance of site-year random effects. There was strong evidence to support the inclusion of site-year random effects in the model (p-value<0.001). The estimated linear mixed effects regression model results are shown in table 3.

{Table 3}

Among the three treatments, the SSP assumed the role of a base treatment category. Results in table 4 indicate when other factors are held constant, the GHP results in lower corn yield than the SSP. This result is statistically different from zero. We find no statistically significant differences between mean corn yields from using the SSP and JDP. These findings corroborate with descriptive statistics in table 1 for years 2014 and 2015 though in 2016, the GHP resulted in higher average corn yield than the JDP. In terms of source of variability in the model, our results suggest that variation that comes from random errors are higher than from the site-years. We further determined actual mean differences among treatments by conducting a post-hoc analysis and results are reported in table 4.

{Table 4}

As found from results in table 3, the SSP would result into about 0.742 Mg more of corn yield per hectare than the GHP, a result that is statistically different from zero at 1%. As earlier explained, there is no statistical significant difference in average corn yield differences between using the SSP and the JDP. While on average, the JDP would result in 0.611 Mg per hectare of corn more than the GHP, the result is not statistically different from zero.

Clearly from the linear mixed effects regression model, the GHP resulted in lower corn yields per hectare than both the SSP and JDP (though the treatment effect between the GHP and JDP was not significantly different from zero), a plausible reason for its lower corn yields could be due to the way it was designed. The GHP is not designed to ensure or enhance seed to soil contact like the SSP and JDP do (see video https://www.youtube.com/watch?v=VisKBsqcCWA). Thus, possibly the SSP's operator used his/her foot to enhance soil to seed contact whereas soil to seed contact was less than ideal for seeds dropped by the GHP. The JDP has press wheels designed to enhance seed to soil contact. Another limitation of the experiment is that unlike conventional practice in developing countries, only one seed was dropped per hill with the SSP. A third limitation is that within row spacing was uniform for all treatments. Thus, the seeding rate was held constant and findings from the experiment cannot be used to address the potential for seed savings with the GHP relative to the SSP.

Following Martin et al. (2005) and Rutto et al. (2014), lack of attention to seed to soil contact when the GHP plots were seeded may have contributed to lower emergence rates for GHP relative to SSP and JDP and the resultant lower crop yield on the GHP plots. As shown in table 5, the GHP resulted in lowest corn emergence rates among the three treatments in all the years and possibly it also failed to place a seed.

{Table 5}

Next are results of an economic analysis of the GHP. Based on a partial budget, our results suggest that for a GHP priced at $50 to be an economically viable alternative to the SSP, it should be able to increase corn yields by at least 0.028 Mg (equivalent to 28 kg) per hectare. *Ceteris paribus*, such an increase of corn yields per hectare would result in a farmer to breakeven relative to using the SSP. In terms of seed savings, results indicate that such a GHP would also be an economically viable planting method if it were able to reduce amount of   seeds by 9,022 per hectare (about 12.19% less). This finding also implies that for the GHP that costs $50 result in equivalent net returns as the SSP, it should enable the smallholder farmer to save corn seeds valued at about $5.0 per hectare (assuming seeds are valued as $1.5/kg).

In terms of labor savings, results suggest that for the GHP valued at $50 to generate equal net returns as the SSP, it is required to reduce at least about 1.933 man-days of labor for planting.

Stated differently, this implies that for the GHP to enable a farmer to break-even, it should reduce the amount of labor required for planting by at least 1.933 man-days.

{Table 6}

Since the value of the GHP would depend on its production and transactions costs, its market price would perhaps be different from the one we assumed above, which would ultimately alter our partial budgeting results. Considering such potential disparity and holding other factors fixed, we present breakeven values of corn yield, labor and seed at varying market prices of the GHP in table 6. We assume that the GHP's market price would range between $40 and $100 per unit. If the price of the GHP was $95 per unit, for it to produce same net returns as the SSP, the GHP would be required to increase corn yields by 0.052 Mg per hectare or result in seed savings of 17,142 seeds per hectare (about 23.16% less), *ceteris paribus*. Similarly, it would have to reduce labor man-days required for planting corn by about 3.7 man-days per hectare. Whereas if the market price of the GHP was $40 per unit, the breakeven values for seeds, labor and corn yields would be 7,218 seeds per hectare (about 9.75% less), 1.547 man-days per hectare, and 0.022 Mg per hectare, respectively[2].

5.0 Conclusion

Corn (*Zea mays* L.) is an important source of food for millions of people, especially in developing countries where it is a staple food crop. Site years of data were produced in field trials conducted at experiment stations in Payne County, Oklahoma.

The GHP was found to result in significantly lower corn yields relative to the SSP. We noted its lack of a mechanism to ensure seed to soil contact once the seed is dropped in the soil

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[2] Omara et al. (2015) posit that if the market price of the GHP was $40 per unit, it would be more marketable among smallholder farmers in the developing world.

as a cause for concern. This possibly contributed to lower corn emergence levels which perhaps contributed to lower corn yields from plots where the GHP was used. In terms of seed savings, we found that a GHP valued at $50 would be expected to increase corn yields by 0.028 Mg per hectare or save about 9,022 seeds per hectare (about 12.19% less) to result in net revenue equivalent to that from the SSP. Such a planter would also be required to reduce labor man-days by 1.933 for it to be economically as viable as the SSP. Since the GHP's market price would vary, we found that the GHP sold at higher market price would also require higher breakeven values for yield, seed and labor, which is expected for a rational producer.

The GHP as used in the field trials failed to perform as well as the SSP. Given these findings, it would not be appropriate to recommend that farmers purchase and use a GHP to replace a SSP. Given the potential for the GHP to reduce seed costs and reduce potential health risk relative to the SSP, we recommend that additional field trials be conducted with the following changes. First, either the GHP should be modified to enhance seed to soil contact when seeding, or the GHP operator should cover and step on the soil above each placed seed. Second, within row distance between seed drops should be doubled in the SSP plots relative to within row distance between seed drops in the GHP plots to more nearly simulate farmer practice. Third, two seeds should be dropped at each location in the SSP plots relative to one seed in GHP plots. The second and third recommendations would more nearly simulate corn planting practices used by Zambian small holder farmers. These changes would not only enable equal seeding rates per hectare for both the SSP and GHP plots and reduce potential confounding effects of unequal seeding rates, but would also boost the GHP's capacity to generate the required breakeven labor, corn seeds, and corn yield values.

One caveat of the study is that consequences of physical contact between treated seed and SSP and GHP laborers were not determined. The GHP has the potential to reduce the negative consequences to operator health resulting from handling treated seed. Additional research would be required to quantify this potential benefit from using a GHP rather than SSP. Furthermore, partial budgeting can only estimate possible financial effects, and not assure them. Management decisions can change the projected impacts and therefore future studies should focus on repeating the analysis using different assumptions which would render more ideas about the risk involved in adopting the GHP.

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Table 1: Descriptive Statistics of Corn Yield (Mg ha^{-1}) According to Planter Type Obtained in 2014, 2015, and 2016

	2014		2015		2016	
Planter Type	Mean	SD	Mean	SD	Mean	SD
SSP	6.683	0.511	4.506	2.140	5.462	2.320
GHP	5.583	0.909	3.421	2.313	5.326	2.291
JDP	6.433	1.357	4.488	1.845	5.221	2.268

Table 2: Descriptive Statistics of Corn Yield (Mg ha^{-1}) by Planter Type from Efaw, Lake Carl Blackwell and Stillwater Agronomy Research Stations

	Efaw		Lake Carl Blackwell		Stillwater	
Planter Type	Mean	SD	Mean	SD	Mean	SD
SSP	6.313	2.268	4.067	1.511	4.050	0.750
GHP	5.582	2.200	3.106	2.173	3.577	0.985
JDP	5.940	1.677	3.706	2.029	5.233	0.451

Table 3: Linear Mixed Effects Regression Results of Corn Yield (Mg ha^{-1}) Response to Planter Type

Variable name	Coefficient	Std. Error
Intercept	5.262***	0.776
GHP	-0.742***	0.346
JDP	-0.130	0.456
Site-year random effect	2.536***	1.262
Error variance	3.388***	1.357
Log likelihood ratio	-408.344	

***Statistically significant at 1%,

Table 4: Least Squares (LS) Means (Mg ha^{-1}) by Planter Type

Planter *i* vs Planter *j*	Difference in Least Squares Means (Mg ha^{-1})
SSP vs JDP	0.130
SSP vs GHP	0.742***
JDP vs GHP	0.611

***Statistically significant at 1%

Table 5. Average Emergence Rates (%) According to Planter Type Obtained in 2014, 2015, and 2016

	2014		2015		2016	
Planter Type	Mean	SD	Mean	SD	Mean	SD
SSP	89.333	17.282	96.565	5.010	91.167	5.734
GHP	82.056	21.421	80.372	14.372	86.020	9.411
JDP	87.333	14.224	92.288	10.461	95.583	4.641

Table 6: Breakeven Corn Yield (Mg/ha), Corn Seed (kg/ha) and Labor Savings (man-days)

Price of GHP ($/unit)	Breakeven Corn Yield (Mg/ha)	Breakeven Amount of Seed (kg/ha)	Breakeven Amount of Labor (man-days/ha)
40	0.022	2.578	1.547
45	0.025	2.900	1.740
50	0.028	3.222	1.933
55	0.030	3.544	2.127
60	0.033	3.867	2.320
65	0.036	4.189	2.513
70	0.039	4.511	2.706
75	0.041	4.833	2.900
80	0.044	5.156	3.093
85	0.047	5.478	3.287
90	0.050	5.800	3.480
95	0.052	6.122	3.673
100	0.055	6.444	3.867

Figure 1: The Greenseeder Hand Planter

Source: Oklahoma State University's Nitrogen Use Efficiency website (www.nue.okstate.edu)

Note: Countries marked in red have some farmers that received a GHP in previous 5 years.

Figure 2: Distribution of the GHP across the World by 2016.

Source: Oklahoma State University's Nitrogen Use Efficiency website (www.nue.okstate.edu)