OPTIMAL NITROGEN FERTILIZER APPLICATION AND EFFICIENT WATER USE

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Abstract
The aim with this study in the Thabu Nchu district of South Africa was to determine the optimal nitrogen (N)-fertilizer application rate for dry beans and maize when using the Infield Rain Water Harvesting (IRWH) technique. The Weighted Least Square (WLS) technique was applied to estimate quadratic production functions based on experimental data for 2004 and 2005. The WLS result confirms that dry beans were strongly affected by N-fertilizer application as well as by the interaction between other variables. This implies that small-scale farmers around Thaba Nchu need to adopt not only IRWH, but also apply an appropriate N rate to improve their food security and livelihood status. The determinants of the maize yield analyses show that N-application, N-square, year effect and location were the only statistical significant factors determining higher maize yields at the one percent test level. This indicated that maize yield was predominantly determined by other, unexplained agronomical factors, requiring further study. The study confirms that farmers need information on the fertility of their land, appropriate N-application rate and proper crop selection to reap benefits when adopting the IRWH farming technique.

*Keywords**:** farming technique, fertilizer application and WLS*

Introduction

Sub-Saharan Africa is amongst the regions in the world where, overall, livelihoods and food security continue to deteriorate. Over the past 14 years, the number of Africans living below the poverty line has increased by 50% (Adebayo, 2004). The majority of Africans still face widespread rural poverty, worsening food insecurity and degradation of the natural resources on which their farming systems depend. According to the Forum for Agricultural Research in Africa, half the population of Africa (340 million people) lives on less than a dollar per day (FARA, 2004).

Seventy percent of the population (430 million people) lives in rural areas and more than 90% of these rural dwellers live on small-scale farms. The economies of sub-Saharan Africa are essentially based on agriculture, but over several decades, the region has faced a structural food deficit. In 2002, Africa received the highest per capita quantity of food aid, amounting to about three million tons (Viljoen *et al*., 2001). However, such a level of dependence on food aid is untenable over the long-term.

In South Africa, about 16 million people live in poverty. The incidence is highest in rural areas. It is estimated by the National Department of Agriculture that 72% of poor people live in rural areas and that about 70% of rural people are poor and food insure (National Department of Agriculture, 1998). Moreover, South Africa is not richly endowed with natural agricultural resources. It has a total surface area of 122 million ha, of which almost 86% is used for agriculture; 74% being natural veld and 14% arable land. About 1,3 million hectares are under irrigation. Rainfall is generally low, unevenly distributed and unreliable. Nearly 91% of the country is arid, semi-arid or dry (National Department of Agriculture, 2003).

The occurrence of poverty in the country is uneven in its spread and intensity. Gauteng and the Western Cape are wealthier provinces with the least number of poor households at less than 12% each. On the other extreme, the Free State, Eastern Cape and Northern Province have the worst poverty situations. In the middle group is Mpumalanga, KwaZulu-Natal and North West Province. The average household in Gauteng earns about R7 742 per month compared to R2 665 in the Free State. Within the provinces, there is also an unequal level of poverty according to urban and rural location, race and gender (Statistics of South Africa, 2004).

Small scale farmers in the vicinity of Thaba-Nchu, are operating in an environment fraught with high level of risk due to less favoured agro-ecological conditions such as poor quality soil and low and erratic rainfall as well as high variability of prices (Kundhlande e*t al.,* 2004). According to Statistics South Africa (2001), 68% of the households in the Thaba-Nchu area earn less than R800 per month.

The Infield Rain Water Harvesting (IRWH) technique is a farming technique that combines water harvesting, no till and basin tillage to stop runoff on high clay soils at Thaba Nchu. This technique is useful to stop ex-field runoff, maximize infiltration and store the harvested water in the soil surface beneath the basin (Hensley e*t al.,* 2000). This technique can provide an opportunity to increase agricultural production by using water efficiently. Many agricultural scientists agree that with the use of appropriate production techniques, especially those that encourage conservation of water and soil resources, it is possible to increase and sustain agricultural output in semi-arid areas (Hatibu, 2002).

Research that has been done by the ARC and its partners at Thaba Nchu have shown that the IRWH technique has considerable potential to increase crop production, reduce risk of crop failure, improve farmers food security and livelihoods as opposed to the Conventional (Con) production technique. The analysis showed that conventional production had negative financial returns and high levels of risk. The IRWH technique showed positive net present values and benefits cost ratios above 1 and is an improvement over the conventional technique (Kundhlande e*t al.,* 2004). What is not yet included in a yield simulation model, is the contribution of N fertilizer application to improve the value of applying the IRWH technique. This paper is reporting on the insight gained from analyzing two-year experimental data of N fertilizer application at Sediba and Bofulo, two villages at Thabu Nchu.

Objective

The main objective of this study was to carry out an economic analysis to determine the advantage of optimising fertilizer application with an IRHW technique. More specifically the determination of the economic optimum levels of nitrogen (N)-fertilizer application.
An experiment has been conducted at two locations over a period of two years to determine the impact of different levels of N on the yields of maize and dry beans. From these result, the questions that need to be answered were:

- What economic explanation can be given to the data obtained?
- What will be the optimal application rates of N fertilizer for the IRWH technique?

Limitation of the study

- Production function from experimental data collected per ha, might not be reliable to recommend exact N-application to the whole farm level; because factors at the farm level might not the same as the experimental area. Experimental data and study data, however, give direction for the farmers to use an approximate level of fertilizer application as point of departure.
- Average yields data collected over shorter period, might not be equal when changes are made at the farm level. The yield result on small plot is most likely to deviate from the whole farm

income, especially on the few years trail. Therefore, it is very necessary to collect data over a longer period in order to estimate closer approximate fertilizer application that leads to targeted yield result.

- The data itself especially from Bofulo area has not reliable to make the right decision for the application of fertilizer maximizing the profit, because the farmers flooded the experiment area.
- In this study, the soil fertility study is not included; therefore, the recommended fertilizer application quantity might be depend on the soil fertility; therefore, this finding of study might not be reliable to all farmers in the area, however, this study serve as stone step as starting for further research.

Literature review

Research has provided evidence that access to an adequate diet depends on access to resources needed for farming that increase productivity, such as adequate fertilizer (Paulina and Carmen, 2002).

Fertilization and correct application of other inputs are essential for efficient crop production in agriculture. Results from various studies, confirmed that balanced fertilizer use leads to over 50% yield increase in agriculture production under suitable conditions. However, non-appropriate (excess, less or incorrect application) fertilizer applications may lead to yield decrease, loss of farmers' income and potential environmental problems. Therefore, the determination of technical, economical and ecologically optimum application of fertilizer is important (Adiku *et al*., 1998).

Crop growth models have and continue to find application in agricultural development and enhancement of the efficiency of field and experimental research (Uehara, 1989). The use of crop models inclusive with water conservation techniques facilitated for the evaluation of different crop production and selection was illustrated by many researchers . For example, Lowen De-Boer *et al.* (1991) used the technique of stochastic dominance to show that the moderate fertilizer application to millet/cowpea intercropping improved both yield and income per hectare under West African Sahel conditions. The ability to produce moderate yields successfully over long periods may override highly profitable but a more risky alternative as long-term sustainability is at stake. Hence, criteria other than economic return need to be included, necessitating to a multi-objective approach, such as Multi-Criteria Approach that take into account all other factors (Janssen, 1992) Jones and Kiniry (1986), for example, developed a production model on maize, which was enhanced to address climatic severity of the semi-arid regions of Australia.

Production functions used with related statistical models are important tools in the explanation of input-output relationships. Directly or indirectly, decisions concerning optimal rates of fertilizer involve fitting a model to describe crop yield response to fertilizers (Doll and Orazem, 1984). Obviously, fertilizer recommendations should be derived using the most appropriate model. Agronomist and agricultural economists are continuously searching for the best model to use. Several different response models have been used over time to identify economic optimum rates of nitrogen (N) fertilization and many researchers have noted that these models often disagree when identifying these rates (Murat and Hasan, 2004).

Literature reviewed showed that farmers are faced with water shortages and also soil fertility problems in semi-arid areas like South Africa (Kundhlande e*t al.,* 2004). Therefore, it is worthwhile for farmers to have information based on experimental data on optimal usage of nitrogen fertilizer application to increase soil fertility and productivity.
For this analysis, a quadratic production function will be fitted to the experimental data and used to analyse the impact of N on the profitability of dry beans and maize when produced with an IRHW technique.

Methodology

In this study the Weighted Least Square (WLS) technique was applied to estimate a quadratic production function for the period 2004 to 2005. Data was obtained from the experimental areas of Sediba and Bofulo at Thaba Nchu. The model used takes the following form:

$$Y_t = C + \alpha_1 N + \alpha_2 N^2 + \alpha_3 D + \alpha_4 L + \alpha_5 DN + \alpha_6 DN^2 + \alpha_7 NL + \alpha_8 DL + \alpha_9 LN^2 + \alpha_{10} DNL + \alpha_{11} DN^2 L \quad [1]$$

Where Y_t is yield in year t, D is dummy variable for the year effect i.e. it takes a value 1 if the data is for year 2005 and 0 otherwise; N is nitrogen fertilizer application and L is location of the experimental area; it takes a value of 0 if the area is located in Sediba and 1 otherwise. The variables DN, DN^2, NL, DL, LN^2, DNL, DN^2L are the impact of the variable D, N, L and N-square interaction among the variables to the higher yield

Where: DN is the interaction between dummy variables of the year effect and nitrogen;
DN^2, is the interactions between dummy variable of the year effect and nitrogen square;
NL is the interactions between nitrogen and location;
DL is the interaction between dummy variable for the year effect and location;
LN^2 is the interaction between location and nitrogen square;
DNL is the interactions between dummy variable for the year effect, nitrogen and location;
DN^2L is the interaction between the dummy variable for the year effect, nitrogen square and location.

The equations shown below are derived from equation 1 to come up with marginal physical productivity equations for each experimental area for each year.

For Bufulo for 2004

$$\frac{\partial Y}{\partial N} = (\alpha_1 + \alpha_7) + (\alpha_2 + \alpha_9)2N \quad [2]$$

For Bufulo for 2005

$$\frac{\partial Y}{\partial N} = (\alpha_1 + \alpha_5 + \alpha_7 + \alpha_{10}) + (\alpha_2 + \alpha_6 + \alpha_9 + \alpha_{11})2N \quad [3]$$

For Sediba for 2004

$$\frac{\partial Y}{\partial N} = \alpha_1 + 2\alpha_2 N \quad [4]$$

For Sediba for 2005

$$\frac{\partial Y}{\partial N} = \alpha_1 + 2\alpha_2 N + \alpha_5 + 2\alpha_6 N \quad [5]$$

After marginal physical productivity equations are derived (equation 2 through to 5), profit maximizing levels of yield (Y^*) and nitrogen (N^*) were calculated (equation 6) by equating marginal value product equations (left-hand side of equation 6) with the price of nitrogen (right hand-side of equation 6). It is assumed that both product and factor markets are perfectly competitive.

$$P_y \frac{\partial Y}{\partial N} = P_N \quad [6]$$

Where P_y is price of Y and P_N is price of nitrogen. Next profit (Π) was calculated, assuming N is the only input used in production, as

$$Y^*{}_t P_y - P_N N^* = \Pi \quad [7]$$

Results

In this section, results on the profit maximizing levels of nitrogen application and yield in dry beans and maize production are be reported. The section has two subsections. The first subsection deals with dry beans, while the second deals with maize.

Determinants of dry beans yield

In this section results on factors affecting dry beans yield are reported. The overall explanatory power is quite high at 77 percent. Except for D and DP (not shown in Table 1) all other variables were found to be statistically significant at the specified level of significance.

Table 1: Factors affecting dry bean yield, 2004-2005

Independent variable	**Estimated coefficient**	**T-ratio**
N	7.56	2.989*
N^2	-93.74	-4.175*
L	-0.51	-9.581*
DN	4.73	1.603****
DN^2	45.31	1.757***
NL	30.58	11.931*
LN^2	-254.17	-10.988*
DNL	-34.12	-10.982*
DN^2L	227.69	8.081*
Intercept	0.7206	13.432*
R^2	0.828	
Adjusted R^2	0.769	
Durbin Watson stat	2.6	
No. observation	44	

, **, * and **** denote significant at the 1, 5, 10 and 20 percent levels respectively*

On the basis of results obtained from Table 1, the techniques described in the methodology section were applied to calculate profit and profit maximizing levels of nitrogen application in the dry beans production for each experimental area for the year 2004 and 2005 (Table 2). According to the results, in the Sediba experimental area, profit of R2 375 and R4 254 would have been obtained with the application of 37 and 120 kilogram of N fertilizer per ha for the years 2004 and 2005 respectively.
The significant deviation of N fertilizer application between the years could be due the interaction between the variables that contributed to increased fertilizer application that needs further agronomical explanation. Similarly, in the Bofulo experimental area, profits of R3 515 and R745 were obtained when applying 54 and 23 kilogram of N fertilizer per ha. The fertilizer application levels were calculated from production the function model derived from WLS. The deviation of fertilizer application between the years is significantly influenced by the year effect that needs further study.

Table 2: Per hectare Gross margin levels of N-application, dry bean yield and profit for Sediba and Bofulo locations for the year 2004 and 2005

Location	Years	Average prices(R/ton)		Gross margin maximizing level of N (ton)	Gross margin level of yield (ton)	Profit (R)
		Price of dry beans	Price of Nitrogen			
Sediba	2004	2 800.00	1 800.00	0.037	0.87	2 374.97
	2005	3 000.00	2 000.00	0.120	1.50	4 254.02
Bofulo	2004	2 800.00	1 800.00	0.054	1.26	3 515.64
	2005	3 000.00	2 000.00	0.023	0.26	7 45.02

Source: Author's calculation

Determinants of maize yield

Factors affecting maize yield are reported in this section. The overall explanatory power is quite high at 79 percent. Except interaction variables PN^2, DNP and DN^2P (not indicated in Table 3) all other variables were found to be statistical significant at the specified level of significance.

Table 3: Linear estimates of maize yield, 2004-2005

Independent variable	Estimated coefficient	"t"
N	14.50	17.04*
N^2	-119.28	-16.72*
D	2.33	5.53*
L	0.64	20.77*
DN	31.93	1.64***
DN^2	-370.91	-2.07**
NL	-2.07	-1.48****
DL	-1.56	-1.28*****
Intercept	0.536	
R^2	0.838	
Adjusted R^2	0.789	
Durbin Watson stat	2.47	
No. observation	48	

*, **, *** *and* **** *denote significant at the 1, 5, 10, 15 and 20 percent levels respectively*

On the basis of results reflected in Table 3, the profit and profit maximizing levels of nitrogen application for each experimental area for the years 2004 and 2005 are shown Table 4. According to the results of WLS, in the Sediba experimental area, profits of R806 and R1 340 would have been obtained with the application of 53 and 45 kilogram of N fertilizer per ha for the years 2004 and 2005 respectively. In the Bofulo area when 44 and 43 kilogram N fertilizer were used, a per ha profit of R1 387 and R2497 would have been obtained. The basic production function equations used to calculate the information in Table 4, are the following for Sediba:

$$\boldsymbol{Y_{2004} = 0.536 + 14.50N - 119.28N^2}$$

$$\boldsymbol{Y_{2005} = 0.5366 + 46.43N - 490.18N^2}$$

Similarly, the respective maize yield equations for the Bofulo experimental data of 2004 and 2005 are:

$$Y_{2004} = 1.176 + 12.43N - 119.28N^2$$

$$Y_{2005} = 1.946 + 44.36N - 490.18N^2$$

Table 4: Optimal per hectare levels of yield, fertilizer N-application and profit for Sediba and Bofulo of maize yield, 2004-2005

Location	Years	Average prices (R/ton)		Gross margin level of N (ton)	Gross margin level of yield (ton)	Profit (R)
		Price of maize	Price of Nitrogen			
Sediba	2004	930.00	1 800.00	0.053	0.97	806.19
	2005	876.00	2 000.00	0.045	1.63	1 340.28
Bofulo	2004	930.00	1 800.00	0.044	1.49	1 387.54
	2005	876.00	2 000.00	0.043	2.65	2 496.69

Source: Author's calculation

Conclusions

From the dry beans yield analyses, (paragraph 5.1), it was shown that most variables were statistically significant at one percent test level. The WLS result confirms that dry beans were strongly affected by N fertilizer application, fertility of land and the interaction between variables.

From the maize yield analyses, (paragraph 5.2), it was shown that N-application, N-square, year effect and location were the only statistically significant factors determining higher maize yields at one percent test level. This indicated that maize yield was predominantly determined by unexplained agronomical factors that need further study to recommend appropriate N-application rates per ha.

This study confirms that farmers need information on land productivity and notably on soil fertility , appropriate usage of N-fertilizer application rate and proper crop selection; to get the most benefit by adopting IRWH farming techniques. This technique has the potential to improve food security and livelihoods of the small-scale farmers of Thaba Nchu.

To get results that are more conclusive, the experiment should be continued so that data over a longer period is obtained. Furthermore, more factors should be included and measured in the experiment. Moreover, farmers are in need of expert assistance to determine technical, economic and ecologic optimum application rates of fertilizer that will enable them to reap the highest benefit from the IRHW farming technique.

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